Department of Agricultural Sciences
Faculty of Agriculture and Forestry
University of Helsinki

Department of Agricultural Sciences Publications 47

INCLUDING NUTRITION IN THE LIFE CYCLE ASSESSMENT OF FOOD PRODUCTS

Merja Saarinen

ACADEMIC DISSERTATION

To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public examination in lecture hall Rasio, Viikki, on 10th December 2018, at 12 noon.

Helsinki 2018

Custos:	**Professor Juha Helenius** University of Helsinki Department of Agricultural Sciences Helsinki, Finland
Supervisors:	**Professor Juha Helenius** University of Helsinki Department of Agricultural Sciences Helsinki, Finland
	Professor Sirpa Kurppa Natural Resources Institute Finland Jokioinen, Finland
	Professor Mikael Fogelholm University of Helsinki Department of Food and Nutrition Helsinki, Finland
	Professor (emeritus) Raija Tahvonen Natural Resources Institute Finland Jokioinen, Finland
Reviewers:	**Professor Sarah McLaren** Massey University University of New Zealand
	Deputy leader of LCA research group **Dr. sc tech., dipl. Ing.-Agr. ET Thomas Nemecek** Agroscope Swizerland
Opponent:	**Ass. Professor Ulf Sonesson** Research Institutes of Sweden Sweden

ISBN ISBN 978-951-51-4668-7 (pbk.)
ISBN 978-951-51-4669-4 (PDF)

Unigrafia
Helsinki 2018

ABSTRACT

Life cycle assessment (LCA) is the most used methodology for assessing the environmental impacts of products, such as food. Comparison between products should be based on a common functional unit (FU). The FU describe a function or functions of the product against which life cycle impacts should be related to. For the food products nutritional value is not typically present in mass-based FUs, which are the most used FUs in current LCA studies. This poses a methodological challenge solving of which this dissertation contributes to. Furthermore, good nutrition is a central sustainability issue per se and thus should be considered alongside environmental impacts while defining sustainable food products.

This dissertation develops and analyses ways to link nutritional aspects into LCA of food so that relevant additional information can be achieved compared to the current LCA practice. Its focus is at analysing the applicability of various different FUs at a product and portion level where a primary consumer choice operates. The alternative FUs are: 1) a mass- or volume-based FU for product per se; meaning that there is no special attention paid to the nutritional quality of product, 2) a mass-based FUs for individual nutrients; meaning that individual nutrients in a product are separately considered, 3) the nutrient indexes of products; meaning that many nutrients in a product are considered at the same time, and 4) standardised portions; meaning the LCA for lunches based on the lunch plate model. The nutrient index approach introduced utilizes a nutrient index based on recommended nutrients used as an FU and combines it with the separate nutrient index based on restricted nutrients. By carrying out this assessment in combination with LCA, sustainable food products can be defined. At product level, a product group specific approach is emphasized, and protein source foods are highlighted as an example of a product group.

All together 66 food products and 29 lunches consisting of 27 food items were assessed using LCA for climate impact as an impact category.

According to the results the use of a nutrient index based on recommended nutrients as an FU is proposed to be, currently, the most suitable general methodology for including nutrition in a food LCA on a product scale. The approach is compatible with the idea of an FU as a description of the benefits of a product. The index which consists of nutrients to be limited is proposed to be combined with these indexes while defining sustainable products. Mass-based FUs for individual nutrients is, instead, proposed to be applied only restrictedly in the cases of scare but essential nutrients which exist only in a few food products.

The use of the standardised portion as an FU provides relevant additional information related to the LCA of individual products, such as meat or vegetables, which alone are not able to provide adequate nutrient

composition intake. The plate model is well-known and the visual element makes it easy to understand. Hence, this kind of FU is particularly usable in generic nutrition and environmental education and counselling.

In the common scientific and popular discourse, the message has been clear when reasoning for sustainable food consumption: one should avoid animal-based foods, particularly beef because beef has by far the greatest environmental impact. According to the results of this dissertation, however, particularly beef, in addition to for example hemp seeds, would benefit from the inclusion of nutrition criteria in food LCA on a product scale. The same issue can partly be seen at a more general level also on the portion scale when nutrition is included in the food LCA. Mixed home-made lunches resulted in 2-6 times more potential climate impacts than vegetarian and vegan lunches. In comparison, the climate impact of beef is 15-fold compared to soybeans (without impacts from land use change) as an uncooked food ingredient in a kilo-basis assessment. The difference between eatable products, i.e. fried beef and cooked soybeans, is only three-fold. According to the assessment on the portion scale, the choice of salad also makes a substantial difference from the point of view of the climate impact if grown in greenhouses. The choice of starch, even rice, was without major implications in the context of the plate model, due to variation in (typical) portion sizes.

Based on the results, the whole picture of the climate impact can be received, only, by including into the assessment 1) the production processes that lead to eatable products and by the inclusion of 2) the combination the functions of the food groups, which have different specific roles in the nutrition. The implications of this aspect should be investigated in more detail on a diet scale: i.e. to what extent beef and other products with high climate impacts and a high nutritional value per kg are relevant for inclusion in a sustainable diet.

In summary, nutrition should be taken into account in versatile ways in the food LCA. Each assessment pattern assessed in this dissertation has its own strength, and vice versa none of the methods can provide an all-inclusive understanding. In this dissertation, the index approach was applied to foods regarded as protein sources, but further research is needed on applying this to other food groups in a product group specific approach. Furthermore, evaluation of the lunches in relation to an application of the nutrient index for meals should also be done in further research. Finally, the approaches in this dissertation are linked to the diet level by specific features or on a knowledge-basis, but to gain an overall picture of the nutrition, health and the environmental impacts of food consumption, a comprehensive assessment on a dietary scale is needed. In dietary scale research, it is important to include the product system required to achieve eatable products, including the preparation phase, so that all ingredients and energy use are taken into account. Strategic self-sufficiency of nutrition has an imperative role in every nation; therefore such research should be ongoing in Finland, too.

ACKNOWLEDGEMENTS

During this study, I worked as a researcher at the Natural Resources Institute Finland Luke (formerly Agrifood Research Finland MTT) and was a PhD student at the University of Helsinki. I am grateful for the opportunity these organisations have given to me. I would truly like to thank my supervisors, Professors Juha Helenius and Mikael Fogelhom from the University of Helsinki, and Professors Sirpa Kurppa and Raija Tahvonen from Luke for their plentiful inspiration and for the support I have received during this journey.

In addition to these organisations and persons, this research was carried out in cooperation with Environmental Institute Finland SYKE and Consumer Research Center KTK, particularly with my co-authors Development Manager, PhD Ari Nissinen and Research Manager, PhD Johanna Mäkelä from those organisations. Nowadays, KTK has been merged with the University of Helsinki, but during our cooperation it was still a research organisation under the Ministry of Trade and Foreign Affairs. Accordingly, Johanna now works at the University of Helsinki as Professor of Food Culture. I am thankful to both of you for the fruitful co-operation and inspiration.

I would like to thank the pre-examiners of the dissertation, Professor Sarah McLauren and Doctor Thomas Nemecek, and reviewers of the articles of this dissertation for invaluable comments I received.

It has been a pleasure to work with my colleagues in Luke. Some of them are also my co-authors in some of the articles of this dissertation. I would like to thank everyone for the co-operation, discussions, and so much more.

This study received funding from the Finnish Ministry of Agriculture and Forestry. In addition to the funding, I am particularly grateful to Consulting Official Suvi Ryynänen for being a chair of the steering group of the most important research project related to this dissertation. There were several Finnish food companies participating in that steering group and also other projects related to this dissertation. I would like to thank all of you for your interest in this research topic and for the invaluable comments you all provided.

At last but not least, I would like to acknowledge and thank my family. I know I have been absent-minded too many times during the past years. In the end, you mean everything to me.

Hämeenlinna, November 2018

Merja Saarinen

Merja Saarinen

CONTENTS

Abstract....3

Acknowledgements....5

Contents....6

List of original publications....9

Abbreviations....10

1 Introduction....12

2 Review of Literature....16

2.1 State of the art in food Life Cycle Assessment....16

2.1.1 Basic features of Life Cycle Assessment....16

2.1.2 Functional unit as a crucial feature of comparative Life Cycle Assessment....20

2.1.3 State of the art in the applications of food Life Cycle Assessment....21

2.2 Nutritional education for consumers and nutrition guidelines....23

2.2.1 Framework for approaches of nutritional education for consumers....23

2.2.2 Nutrition recommendations/The Finnish Nutrition Recommendations....26

2.2.3 The Plate Model....28

2.2.4 Nutrient indexes....28

2.3 Nutrition in a current food Life Cycle Assessment and development needs....29

2.3.1 Whole diet scale....29

2.3.2 A meal scale....31

2.3.3 A product scale....33

2.4 The approach of this study....35

3 Objectives of the study....36

4 Materials and methods 37

4.1 Selecting nutrient indexes 38

4.2 Case-products 40

4.3 The Life Cycle Assessments 42

4.4 Functional units 43

4.4.1 Functional units based on standardised lunch 44

4.4.2 Correlation test for functional units at product level 45

4.4.3 Functional unit based on quantity of individual nutrients..46

4.4.4 Functional unit based on nutrient indexes for a product 47

4.5 A method to identifying sustainable food products 49

5 Results 51

5.1 Traditional Life Cycle Assessments for products 51

5.2 Life Cycle Assessments for standardised lunches 51

5.3 Life Cycle Assessments for food products with linking nutrition in the assessment 55

5.3.1 Correlation test 55

5.3.2 GWPs per quantity of products, nutrient indexes for products, Reference Flows for nutrient indexes and Reference Amounts for Daily Recommended Intakes 56

5.3.3 A method for distinguishing between sustainable and unsustainable food products 58

5.4 Evaluation of the approaches 59

6 Discussion..63

6.1 How can nutrition be integrated to food LCA? 63

6.2 What kind of question can these approaches answer? 67

6.3 What kind of information can the approaches provide? 70

6.3.1 Rising awareness of environmental impacts of food using standardised lunch 70

6.3.2 Optimizing intake of scarce nutrients with the lowest environmental impacts 72

6.3.3 Distinguishing between sustainable and unsustainable products by using GWP/nutrient index and LIM measures 73

6.4 What preconditions and challenges does an assessment have when these approaches are applied? 75

6.4.1 System boundaries and bio-waste 75

6.4.2 A need to identify the reference flow 76

6.4.3 Data quality requirements 77

6.5 Do different approaches result in different outcomes and interpretation of the climate impact of food products? 78

6.5.1 Influence of using individual nutrient - or nutrient index - based FU 79

6.5.2 Influence of using method to define sustainable products and standardised lunch 80

7 Conclusions 82

7.1 General conclusions 82

7.2 future research 84

References 86

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I Usva, K., Saarinen, M., Katajajuuri, J-M., Kurppa, S. 2009. Supply Chain Integrated LCA Approach to Assess Environmental Impacts of Food Production in Finland. Agriculture and Food Science 18, 3-4, 460-476. http://urn.fi/URN:NBN:fi-fe2015090311162.

II Saarinen, M., Kurppa, S., Virtanen, Y., Usva, K., Mäkelä, J., Nissinen, A. 2012. Life cycle assessment approach to the impact of home-made, ready-to-eat and school lunches on climate and eutrophication. Journal of Cleaner Production 28, 177-186. DOI 10.1016/j.jclepro.2011.11.038.

III Saarinen, M., Fogelholm, M., Tahvonen, R., Kurppa, S. 2017. Taking nutrition into account within the life cycle assessment of food products. Journal of Cleaner Production 149, 828-844. DOI 10.1016/j.jclepro.2017.02.062.

The publications are referred to in the text by their roman numerals.

The contribution of the authors in the original articles of this thesis is presented in the following table:

	I	II	III
Planning of the study	MS, KU	MS, JM, SK	MS, MF, RT
Data analyses, modelling	KU, MS	MS, KU, YV	MS
Interpretation of results	MS, KU, SK, JMK	MS, SK	MS, MF, RT, SK
Manuscript preparation	KU, MS, SK, JMK	MS, SK, JM, AN	MS, MF, RT, SK

ABBREVIATIONS

LCA	Life cycle assessment
GWP	Global warming potential
FU	Functional unit
IPCC	International Panel of Climate Change
FNR	Finnish Nutrition Recommendations
FBDG	Food-based dietary guidelines
NBDG	Nutrient-based dietary guidelines
DALY	Daily Adjusted Living Years
DRI	Daily recommended intake (equal to DRV; used regularly in LCA literature)
DRV	Daily reference value (equal to DRI; used regularly in nutrient recommendations and in nutrition science)
DA	Daily allowance
EAA	Essential amino-acids
RF	Reference flow, flows of substances, mostly foods or nutrients in this dissertation, needed to fulfill FU or unit of nutrient index
RA	Reference amount, amount of food needed to fulfill DRI for a nutrient

1 INTRODUCTION

Environmental detriments are faced both globally and locally. Industrialized forms of agriculture, alongside our reliance on fossil fuels, have been main drivers towards an unsustainable situation (Rockström et al., 2009). Food production and consumption are strongly linked to practically all the environmental detriments and critical planetary boundaries (Rockström et al., 2009; Steffen et al., 2015), but most essentially to biochemical flows, land-systems and genetic diversity.

Environmental impacts of food production and consumption can be assessed in various ways. The basic means for distinguishing between different assessments are the classifications of an action- or site-based (vertical) and a life-cycle-based (horizontal) assessment. In contrast to action- or site-based assessments, a life-cycle-based assessment of product takes into account impacts not only from actions at the site of production but also includes impacts from input industry and transportation needed for the production. In the life-cycle assessment (LCA), which is an established and widely used life-cycle-based assessment method, emissions and related environmental impacts are also allocated to the amount of production they represent, resulting in a measure of environmental efficiency. This approach provides insight into environmental impacts along the production chain or web, but they typically lose touch with absolute impacts and carrying capacity of a target environmental element. The strength of the approach is in its suitability for comparisons particularly at the product level.

Food consumption is a complex and sensitive issue. Ultimately, it maintains the physical ability to function, reproduce, grow and survive by providing the energy needed and the essential and beneficial nutrients, but on the other hand, too high an intake of energy or some of the nutrients is associated with negative health impacts. These nutrients with negative health impacts in typical portions are commonly referred to in food education nutrition guidelines and literature as nutrients to be limited or restricted, disqualifying or harmful nutrients. Individual foods, substances that we eat, typically contain both essential or beneficial and harmful nutrients. While nutrients relate to individual foods or diet, i.e. what we eat, nutrition illustrates the state of an individual or a nation, for example, regarding nutrient intake. It can also mean a corresponding abstract concept. Beyond nutrition, food expresses culture and it offers pleasure directly via tasting experience and indirectly via social intercourse related to eating, making food consumption even more complex.

In safeguarding human health (Whitmee et al., 2014), a very strong message has been given: "A fundamental principle for the improvement and maintenance of human health should address present inequities in health and protect the health of future generations as far as possible while preserving the integrity of the biophysical systems, upon which humanity ultimately depends." While biosphere integrity is not yet quantifiable in the planetary boundary context (Steffen et al., 2015) nor in LCA, climate change has a more robust quantitative basis. Therefore, global warming potential (GWP) is one of the most commonly used impact indicators in LCA. Food production and consumption have a significant impact on climate. Food consumption from "farm to fork" accounts for 20-30 % of climate impact causing greenhouse gas emissions human of origin, globally (Tukker et al., 2011). The livestock sector solely accounts for 14.5 % of global emissions, from which 65 % come from ruminants (FAO, 2017a). Total greenhouse gas emissions related to food production are forecasted to rise with global population increase (Tilman and Clark, 2014); however emissions from other human activities have been growing even faster (FAO, 2017b). In Finland, 9-14 % of climate impact is caused by agricultural and food production (Seppälä et al., 2011; Virtanen et al., 2011). Food, in turn, accounts for 21 % of the GHG emissions of household consumption (Seppälä et al. 2011).

The environmental impacts of food production clearly have to be reduced globally. It is, however, not enough to make food production more eco-efficient, but food consumption also has to be changed (Bryngelsson et al. 2016; Garnett, 2011). A dietary change to a more eco-efficient diet is crucial particularly in western industrial countries. At the same time, ongoing dietary change in the developing countries should not continue towards diets with low eco-efficiency, such as the western kind of diet – as it is currently doing. Both diets and ways of producing them should be developed towards eco-efficiency (Garnett, 2011), acknowledging the fact that such environmental adaptations can only push (population) growth further but not remove its limits.

Dietary change is a challenging task. Consumption, including food consumption, relates strongly to the everyday life of people, and its practices (Warde, 2005). According to the theories of practice, "a 'practice' is a routinized type of behaviour which consists of several elements, interconnected to one another: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge." (Reckwitz, 2002, 249). Thus, practices consist of both doings and sayings; understandings, procedures and engagements (Warde, 2005). According to Warde (2005), "consumption might be considered a dispersed practice, one that occurs often and on many different sites, but is not an integrated practice. People mostly consume without registering or reflecting that that is what they are doing because they are, from their point of view, actually doing things like driving, eating or playing. They only rarely understand their behaviour as 'consuming'". Consumption is thus not itself a practice but is a part of almost every practice. Theories of practice emphasize processes like habituation, routine, practical consciousness, tacit knowledge and tradition, and according to these theories, performance in a familiar practice is often neither fully conscious nor reflective (Warde, 2005). This kind of view of food consumption forms a framework for this dissertation. It appears particularly in Article II, where a communication tool is developed, but it also indirectly affects the ultimate goal of this dissertation to include nutrition in food LCA, because nutrition and the role of nutrients in the different kinds of foods relate profoundly to food consumption and eating as a practice (although there are also other factors affecting eating).

Total sustainability of food is, however, beyond the environmental impacts and resource sufficiency of food production. According to the European Commission (EU, 2016): *"For food, a sustainable system might be seen as encompassing a range of issues such as security of the supply of food, health, safety, affordability, quality, a strong food industry in terms of jobs and growth and, at the same time, environmental sustainability, in terms of issues such as climate change, biodiversity, water and soil quality."* Particlularly protein has been a topic of self-sufficiency and dietary discussion since the 1970s. At first this included the protein gap, which was later strongly questioned (Semba 2017), leading at present to a lively discussion on novel protein sources and ingredients and their prospects for commercialisation (Henchion et al., 2017). These various issues should be considered in parallel, but the task is naturally challenging.

Good nutrition is a central sustainability issue. Food and nutrition are related to several of the UN's sustainable development goals, particularly goal number 2 *Zero hunger*, number 3 *Good health and well-being*, and number 12 *Responsible consumption and production* (UN, 2015). All these goals emphasize dietary change to more sustainable diet.

There are several definitions of a sustainable diet (Garnett, 2014). FAO's (2010) definition is one of the most all-inclusive: "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."

A sustainable diet consists of food products which are in accordance with a sustainable diet. The LCA offers a solid framework to assess sustainability impacts of products. The LCA approach provides valuable information for consumers and production chain players, both acting as decision makers who can steer consumption and the production of food to be more sustainable. The most established and widely used LCA methods are for the assessment of environmental impacts, while methods for the assessment of other sustainability impacts, for example social impacts, are much more in their infancy. However, current practice concerning environmental LCA for food products largely ignores the nutritional quality of food (Nemecek et al., 2016; Notarnicola et al., 2017a), although it is a fundamental feature of food. This ignorance is one of the largest weaknesses in the current practise (Notarnicola et al., 2017a) and is thus one of the most important development tasks in a field of food LCA. In the longer run, this is also a question of equity approaching what the trade-off should be between a highly nutritional diet and environmental and social impacts somewhere along the global supply chain.

2 REVIEW OF LITERATURE

2.1 STATE OF THE ART IN FOOD LIFE CYCLE ASSESSMENT

2.1.1 BASIC FEATURES OF LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a baseline methodology to assess life cycle impacts of products and services. LCA means that ideally the entire production-consumption system is considered; it is also called a cradle-to-grave approach. In practice, narrower system boundaries are also applied: in food LCA for individual products (e.g. Baldini et al., 2016) and even for diets (Pernollet et al., 2016) the product system is often used for the stream up to retail or just to the farm gate, and thus excluding for example a consumer/use phase.

LCA is based on the International Standard 14040 –series (ISO 14040:2006; ISO 14044:2006), and several further methodological developments have been carried out and guidelines have been published, such as the ILCD (The International Reference Life Cycle Data System) handbook published by the European Commission Joint Research Centre (EU/JRC, 2017). The ILCD handbook consists of a set of documents that are in line with the ISO 14 040 –series (EU/JRC, 2017).

Initially LCA covered only environmental aspects, but is now extended to socio-economic issues (UNEP/SETAC, 2009) and societal life cycle costs (UNEP, 2011; UNEP/SETAC, 2009). While the LCA initially had been developed for the assessment of industrial products, its scope has been widened to include bio-based products such as food (Notarnicola et al., 2012). In recent decades and in recent years the scope has been further broadened to even include organizations (UNEP/SETAC, 2015). On the other hand, the methodology has been challenged by the assessment of bio-based products, as their system boundary includes biological processes to a large extent (Notarnicola et al., 2017a; Soussana, 2014). The improvements, in this sense, are dealt with more in detail in section 2.1.3.

Players in production chains can improve their environmental performance and their performance in other areas of responsibility by using LCA which is based on extensive primary data, i.e. production-chain-specific data (e.g. Katajajuuri et al., 2014; Article I), and a wide range of impact categories. Doing so reduces the risk of partial optimization, because the entire production-consumption chain and relevant categories are included in the assessment, and based on that, related hotspots can be identified. Information produced by the LCA can be utilized – and is utilized - also in consumer (e.g. Jungbluth et al. 2000; Nissinen et al., 2007) and customer (Schau and Fet, 2008) information. LCA is also very much utilized as a science-based research method nowadays, and a majority of the scientific literature on the food LCA provides scientifically sound knowledge on the sustainability of products (see more in sections 2.1.3 and 2.3). This method often relies on so called secondary data, which means general level data, such as national or sector-wise statistics, extrapolative data from LCA databases and LCA literature, etc. These kinds of studies provide relevant information particularly for educational and political purposes.

The LCA can be comparative or descriptive both in chain specific assessments for certain products and in more general level assessments for average products (ISO 14 040-series). Another borderline is between attributional and consequential LCA (Earles and Halog, 2011; Hospido et al., 2010). While attributional LCA is descriptive of material and energy flows along the production-consumption chain and the related impact on the environment, the consequential LCA assesses consequential environmental impacts of decisions in the context of markets. As they have different orientation, they can be seen as complementary approaches.

As an assessment practice LCA includes four main stages: scope and goal definition, inventory assessment, impact assessment and interpretation. The scope and goal definition consists of a description of the product to be assessed, the aim(s) of the study, and the methodological decisions and definitions to be used in the study. The main methodological decisions include the setting of system boundaries, the choice of functional unit (FU) or units, definition of data requirements, and the choice of impact categories and impact indicators to be used in the impact assessment stage. The setting of system boundaries includes decisions on the phases and processes which are intended to be included in the study as well as inputs to them and outputs from them. Figure 1 outlines the coverage of a typical food LCA: a product system and coverage of inventory assessment, impact assessment and life cycle interpretation.

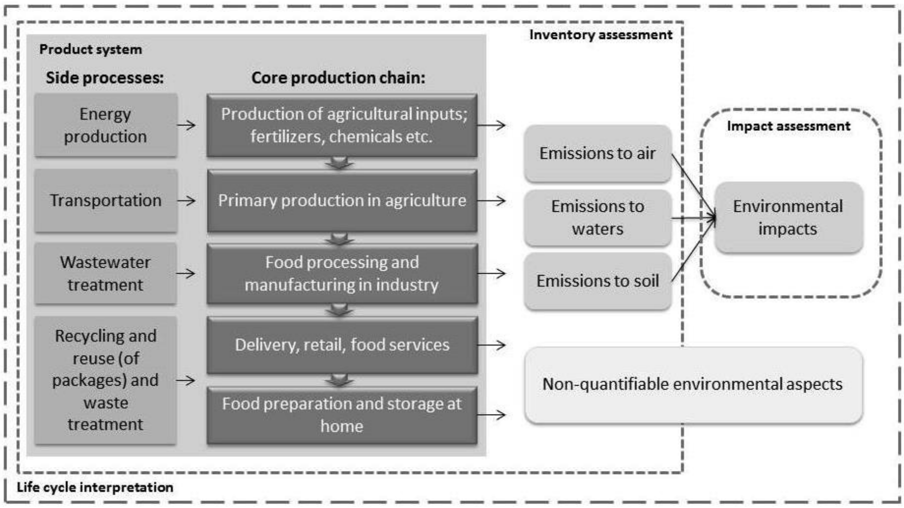

Figure 1. Coverage of a typical food LCA. Illustration of system boundaries of a product system in a typical food LCA, and coverage of inventory assessment, impact assessment and life cycle interpretation respectively stylized according to ISO 14000:2006 and ISO 14044:2006. A product system includes core and side processes during the life cycle of a product "from cradle to grave". A product is produced in the core production chain step by step via intermediate products from phases in the production chain, ending in the consumption of the final product in the use phase at home (or other consumption place, such as a restaurant or canteen). The wide arrows in core production chain illustrate product(s). The inventory assessment collects data on material and energy flows linked to the processes, and measures, models or calculates the related emissions, and allocate material and energy flows and emissions to related products, which have also been identified and quantified in the inventory assessment. Material and energy flows are not explicitly visible in the picture, but they belong inherently to the processes. Emissions are characterized as impact category results in the impact assessment phase. Alongside this quantitative assessment other, usually non-quantifiable environmental aspects are identified. All this information is interpreted during the work and is finally used to form conclusions about the environmental impacts of a product.

The inventory phase consists of selecting the data sources, data extraction and measurements, and calculation or modelling the emissions of different operations in the life cycle of the product. In the impact assessment phase, emissions are classified and characterized according to the chosen impact assessment method, i.e. the emissions are aggregated using specific characterization factors. According to the LCA standard, classification and characterization are mandatory for all LCA studies (ISO 14040:2006; ISO 14044:2006). Impact indicators operating in this level are called midpoint indicators (Amani and Schiefer, 2011; Bare et al., 2000; Bare and Gloria, 2008; EC/JRC, 2010). They do not give information about change or damage in the target environmental system but represent potential impacts. To go further, normalization and aggregation of the midpoint impacts can also be applied by making value judgements for the midpoint impacts. In that case, an impact assessment is based on endpoint indicators (Amani and Schiefer, 2011; Bare et al., 2000; Bare and Gloria, 2008; EC/JRC, 2010). These indicators illustrate change in the target environmental element or system (i.e. the target to be protected). Parallel use of midpoint and endpoint indicators is recommended (EC/JRC, 2010).

If midpoint indicators are used the final outcome of the assessment is typically expressed in equivalents, for example CO_2 equivalents for climate impacts and PO_4 equivalents for potential eutrophication (EC/JRC, 2010). Endpoint indicators are not as well established as midpoint indicators and thus they are not used as frequently. They also vary considerably with the assessment methods. They could consist, for example, of damage points for ecosystem damage or Daily Adjusted Living Years (DALY) for human health impacts (EC/JRC, 2010).

According to the LCA standard (ISO 14040:2006; ISO 14044:2006), interpretation is not just an independent, final phase of the study but it is present in all phases of the LCA. LCA is an iterative method, and so it utilizes information gained and understanding grown along with the work and goes backwards if needed. For example, uncertainty and sensitivity analyses, which are parts of the interpretation, may lead to a need to collect additional data on a certain part of the product system. The interpretation of the results is done in line with the goal and scope of the study and related methodological choices (ISO 14040:2006; ISO 14044:2006). In the final conclusions on the environmental performance of a product, other environmental aspects related to product system are taken into account alongside the selected environmental impacts which have been quantitatively assessed in the impact assessment (ISO 14040:2006; ISO 14044:2006). Interpretation of results often includes comparison with reference product(s), but it is not mandatory and depends on the goal of the study (ISO 14040:2006; ISO 14044:2006).

An LCA process typically includes various sources of uncertainty related to model imprecision, input uncertainty and data variability (ISO 14040:2006; ISO 14044:2006). There is typically a shortage of good quality data regarding at least some processes in a product system. Emission models utilized for obtaining the emission factors for inputs or activities of product system are often incomplete and the factors may be approximate. According to the LCA standard, uncertainty introduced in the results of an inventory analysis should be quantified in a systematic uncertainty analysis (ISO 14040:2006; ISO 14044:2006). There are a range of methods to be used in uncertainty analysis (Heijungs and Huijbregts, 2004), but a common practice is still developing (e.g. Groen and Heijungs, 2017). Sources of the main uncertainties have to be at least recognized and described in any LCA study.

2.1.2 FUNCTIONAL UNIT AS A CRUCIAL FEATURE OF COMPARATIVE LIFE CYCLE ASSESSMENT

According to the LCA methodology, comparison should be based on consistent methodological choices and, particularly, on a common functional unit (FU) (ISO 14040:2006; ISO 14044:2006). The FU should describe a function or functions of the product to be assessed, and it should be chosen in accordance with the goal and the scope of the study. The features of workable FUs are discussed in Article III.

In general, the choice of the FU is a critical step because the FU conclusively affects the results of the study (Cerutti et al., 2013; Masset et al., 2014; Martínez-Blanco et al., 2010; Salou et al., 2017; van der Werf and Salou, 2015). Recent food LCA studies have concluded, for example, that a mass-based FU cannot properly express all the differences in environmental impacts between intensive and extensive, or conventional and organic, agricultural production, particularly in respect to locally appearing impacts (Cerutti et al., 2013; Salou et al., 2017; van der Werf and Salou, 2015), such as eutrophication and biodiversity. In these situations, an FU based on area, e.g. ha, are suggested alongside mass-based FUs. Utilizing area-based FUs may be a highly relevant approach for local decision-makers, for example. The problem here however is that an area-based FU does not relate directly to the products and thus it prevents comparison between consumer products. Development of more site-specific impact indicators might be needed to solve this problem. On the other hand, economic result can also be of interest from the producers' point of view, for example, and thus the amount of euros earned may be a relevant FU for producers. It is obvious that impacts per unit of earnings are not necessarily correlated with impacts per unit of produced product (Cerutti et al., 2013; van der Werf and Salou, 2015).

Concerning products and the nutritional function of food, the nutritional quality of agricultural products may depend, for example, on the variety, agricultural practices and climatic circumstances (Schreiner, 2005), and thus for a given product, a mass-based FU may confer different LCA results than an FU based on nutritional quality (Martínez-Blanco et al., 2010). The applicability of nutritional FUs is strongly dependent on the data available for the LCA study. For example, Martínez-Blanco et al. (2010) compared the impact of different fertilizing practices to the environmental impacts of cauliflowers using five different FUs, 1 t of commercial yield, 1 commercial fruit, 1 kg of commercial dry matter, 1 kg of sinapic acid derivatives content, and 1 kg total phenol content. This kind of approach demands very detailed data on both practices in the production chain and product quality. It is not applicable in current LCA practice, and hence not applicable for consumer sustainability education or for supporting political decision-making, but it is a very interesting development path.

Energy content is an important nutritional property of food, and thus question is open if that is a relevant basis for determining an FU. An energy-based FU (per J or kcal) would lead to a different outcome to a mass-based

FU (per g) in relation to the nutritional quality of a food product (Masset et al., 2014). Masset et al. (2014) highlighted the role of the scope of the study in choosing a relevant FU by stating that the choice of a functional unit should ultimately depend on the intended application. They concluded that neither energy-based nor mass-based FUs seem ideal and that it may be confusing for stakeholders to see both units coexisting. They analysed these two FUs in relation to nutritional quality of foods and food prices.

However, for the food products nutritional value is not typically present in mass-based FUs, such as kilogrammes or grams, which are the most used FUs in current LCA studies of food products (Schau and Fet, 2008). This poses a methodological challenge which has been increasingly dealt with in LCA studies in recent years. It is further discussed in section 2.3, and it is also focused on in Article III.

2.1.3 STATE OF THE ART IN THE APPLICATIONS OF FOOD LIFE CYCLE ASSESSMENT

An early-stage application of LCA to agricultural products started as early as the 1970s, but full-scale applications to food products started in the 1990s. Development was slow at the outset, but it has exploded in recent ten years. In the beginning, it was about introducing the methodological framework for food products, and lately the subject has been spread and deepened (Nemecek et al., 2016).

Most recently, the focus of LCA food applications has shifted to so called hotspot-products, such as beef (review by de Vries et al. (2015)) and other animal-based products (reviews of milk by Baldini et al., 2017, seafood Cashion et al., 2016, other products Marton et al., 2017; McAuliffe et al., 2016) which are typically much more of burden than plant-based products assessed per mass. Studies have also focussed on more special products (Amienyo et al., 2013; Avadi et al., 2014; Figueiredo et al. 2017; Ingwersen, 2012; Rosa et al., 2017), meat-substitutes (Smetana et al., 2015; Halloran et al., 2016), food ingredients (Draaisma et al., 2013) and comparisons of specific techniques or inputs in production chains (Avadi et al., 2014; De Marco et al., 2015; Figueiredo et al., 2017; Kebreab et al., 2016; Reckmann et al., 2016), or intensity of production particularly in animal production (Ogino et al., 2016; Huerta et al., 2016). Research on food-based bio-waste has also been increasing due to a growing awareness of its magnitude and role in the life-cycle-impacts of the food sector globally (zu Ermgassen et al., 2016; Gutierrez et al., 2017; Hansen et al. 2017; Williams and Wikström, 2011).

There were, and still are, some challenges resulting from the fact that LCA was initially developed for manufactured industrial products. Biological processes in agriculture and their related environmental impacts are crucial to understand in LCAs on food products (Notarnicola et al., 2017a; Soussana, 2014). The basic challenges have been mostly overcome by adapting different kinds of modelling approaches to biological and environmental processes in the inventory analysis (Nemecek et al., 2016), or using commonly accepted assessment methodology, such as IPCC methodology for these processes in the assessment of climate impact. These methods provide a reasonable basis for an assessment in general, but there is still a need for methodological improvement regarding modelling of different production practices, for example organic production (Meier et al., 2016; Notarnicola et al., 2017a), crop rotation (Brankatschk and Finkebeiner, 2015; Goglio et al., 2017) and mixed-production of farm animals and crops (Marton et al., 2017). Also, emission models and impact assessments should be better linked to local circumstances in some impact categories (Notarnicola et al., 2017a), such as eco-toxicity (Rosenbaum et al., 2015) and eutrophication. Additionally, linkage between LCA and natural capital, i.e. the use and maintenance of natural resources, is one of the current challenges related to natural processes (Soussana, 2014).

In terms of data production, LCA is a labour intensive technique, and is thus expensive particularly if it is applied in a production-chain-specific way. As a scientific method LCA has extensively been used to produce generic information about environmental impacts related to products or product categories in order to provide a general view and understanding of focal points of impacts among the food products or along a typical production-consumption chain of a product. Recently, methodological simplicity (e.g. Pernollet et al., 2017) and LCA databases have been requested and databases have also produced (e.g. Nemecek et al., 2015; Wernet et al., 2016). Furthermore, uncertainty and sensitivity analyses related to data use in a study have been highlighted related to this sort of general level LCA (Guo and Myrphy, 2012). This is a relevant approach in general, but it is not sufficient because it does not provide clear enough information to the actors in production chains to form a basis for improvements of their processes, or to consumers to establish a basis for making purchasing decisions between products within a product category (which in turn would provide incentives for making improvements in a production chain). These tasks call for a chain-specific-LCA based on data from the production chain in question.

2.2 NUTRITIONAL EDUCATION FOR CONSUMERS AND NUTRITION GUIDELINES

2.2.1 FRAMEWORK FOR APPROACHES OF NUTRITIONAL EDUCATION FOR CONSUMERS

Nutritional education for consumers and published nutrition guidelines seek to influence consumer knowledge, awareness, attitudes and skills concerning healthy eating (Hawkes, 2013). This area utilizes several approaches and tools (Figure 2). In addition to be utilized as a basis for food, nutrition and health policies the nutrition guidelines are utilized in diet- and health-related activities and programmes and in developing educational materials for consumers and food-related services (Fogelholm, 2016).

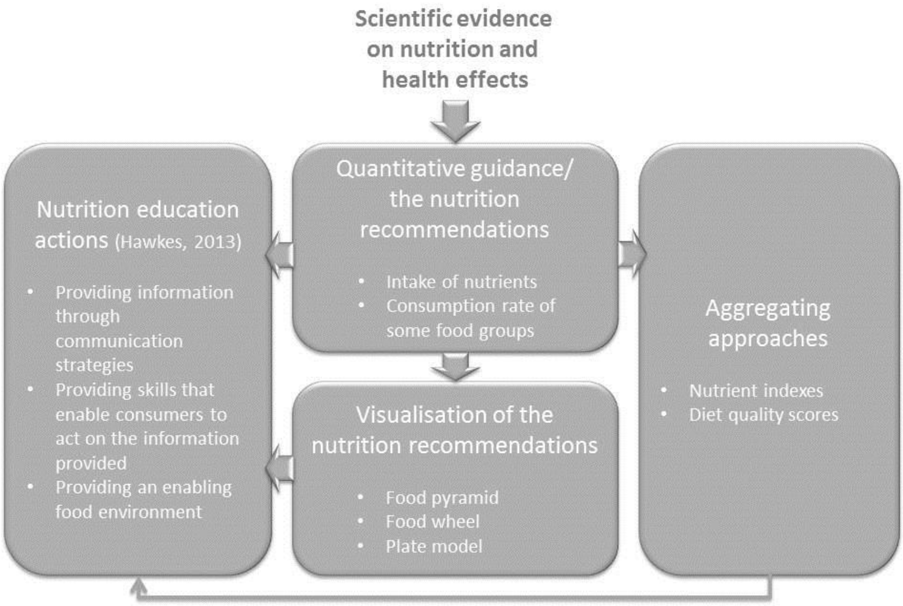

Figure 2. Framework for approaches of nutritional education for consumers and related tools.

At the centre of nutritional education for consumers are nutritional recommendations which are based on scientific evidence on nutrition and its public health effects (Fogelholm, 2016). The nutrition recommendations essentially represent nutrient-based dietary guidelines (NBDG), which include quantitative nutrient-based guidelines on the recommended minimum daily intake of beneficial nutrients and the recommended maximum daily intake of nutrients that are harmful to health in a typical portion (Fogelholm, 2016). The guidelines refer to population reference intakes, average requirements, adequate intake levels and the lower threshold intakes (EFSA, 2017.) In addition to these daily reference values (DRV), the nutrition recommendations often include food-based guidance. These typically include portion sizes and consumption frequencies for foods at the food category level (Fogelholm, 2016), and guidance to increase or reduce the consumption of certain foods, for example to increase the consumption of fruits and vegetables and to reduce the consumption of red meat (e.g. National Nutrition Council, 2014). This type of guidance is typically based on epidemiological evidence, current consumption patterns and related public health concerns (EFSA, 2017; Fogelholm, 2016). The main target of the nutritional recommendations is to provide information to health professionals, nutrition educators, and policymakers, who use this information when working with the general public (Bushman, 2017). The nutritional recommendations (in the NBDG approach) have been converted into additional or substitutive food-based dietary guidelines (FBDG), but they still remain as central nutrition guidelines, for example, in the US (HHS and USDA, 2015) and Nordic countries (Nordic Council of Ministers, 2014).

In many countries, a food-based visual tool for nutrition guidelines has been applied, such as a food pyramid, a food wheel or circle, or a plate model (Montagnese et al., 2015; Smitasiri and Uauy, 2007). Furthermore, the Food and Agricultural Organization (FAO) and the World Health Organization (WHO) have promoted these kinds of tools by producing and updating (all kinds of) FBDGs for two decades already (Clay, 1997). These visual food-based tools illustrate how much different kinds of foods should be consumed on average and proportionally if good nutrition is sought, and so they are supposed to help consumers to establish a healthy balanced diet or meal and to prevent diet-related diseases. In addition to being easy-to-understand, FBDGs can be incorporated into cultural, ethical, social and family meanings of food (Clay, 1997). In that sense FBDGs may be more easily acceptable than NBDGs. On the other hand, it has recently been discovered that foods can include components or other features that are associated more clearly than nutrients with health (Fogelholm, 2016). There are several examples. One of them is that there is growing evidence that microbes affect human health beyond nutrients (Derrien and van Hylckama Vlieg, 2015). Another example is phenols, which are not essential nutrients but may favourably affect the human genome (Alissa and Fwerns, 2017). Phenols also affect the gut microbiome, mostly inhibiting the growth of harmful microbes (Singh et al., 2017). Furthermore, the question may be about the "food matrix", food as whole (Fogelholm, 2016; Thorning et al., 2017), and that actually the entire diet may even play a significant role in shaping the gut microbiome, for example, thus affecting human health indirectly (Portune et al., 2017; Singh et al., 2017). However, there is still a need for advanced scientific knowledge before microbiome-based dietary recommendations, for example, can be established (Portune et al., 2017).

Initially nutrition guidelines have been focused on nutritionally relevant dietary patterns, but recently they have been linked to other sustainability issues, such as cultural acceptability (Monteiro et al., 2015), environmentally sustainable food consumption (Monteiro et al., 2015), and physical activity, in particular (Becker et al., 2004; Monteiro et al., 2015). The development of integrative frameworks, guidelines and practices are still under way, and they have been seldom translated into official government guidelines (Fischer and Garnett, 2016; Hawkes, 2013), and are not usually fully integrated (Fischer and Garnett, 2016). However, wider sustainability issues have been included in the official FBDGs for example in Brazil (Monteiro et al., 2015; Ministry of Health of Brazil, 2014) and Qatar (Seed, 2014). The Finnish Nutrient Recommendations (National Nutrition Council, 2014) represent NBDG (a verbal and quantitative approach), while the Mediterranean Food Pyramid (Mediterranean Diet Foundation, 2017) is a specific visual approach to nutrition guidelines which also includes wider sustainability aspects.

The quantitative nutrition recommendations and the visual tools based on the food-based recommendations provide information and form a basis for nutrition education and even advanced quantitative guidelines (for an example of visualization of a food pyramid, see Mediterranean Diet Foundation 2017). Advanced quantitative guidelines can also be a basis for some nutrition education as these provide information.

According to Hawkes (2013), nutritional education actions consist of three components: 1) providing information through communication strategies (e.g. information campaigns, dietary advice in health service settings), 2) providing skills that enable consumers to act on the information provided (e.g. cookery, human growth), and 3) providing an enabling food environment (e.g. marketing to children, making different foods available). Contento (2008) put the same thing in words: “There are three essential components to nutrition education: 1. A motivational component, where the goal is to increase awareness and enhance motivation by addressing beliefs, attitudes through effective communication strategies. 2. An action component, where the goal is to facilitate people’s ability to take action through goal setting and cognitive self-regulation skills. 3. An environmental component, where nutrition educators work with policymakers and others to promote environmental supports for action.”

Nutrition education is delivered by multiple practitioners, such as private and public sectors and civil society, and it takes place in different settings ranging from public sector canteens to grocery shops and homes (Hawkes, 2013). Both foods (e.g. fruits and vegetables) and nutrients (e.g. fats, vitamins) can be included in the actions reacted to nutrient education (Hawkes, 2013).

Advanced quantitative approaches are based on nutrient recommendations but elaborate them further so that the information is more aggregated and thus probably easier to understand and apply in every day decision making and in building scientific knowledge. Diet quality scores

(Waijers et al., 2007), the Healthy Eating Index, HEI (Kennedy et al., 1995; Guenther et al., 2013) and various nutrient indexes and nutrient profiling schemes (Azais-Braesco et al., 2006; Drewnowski and Fulgoni, 2014) are good examples of this kind of approach. The HEI includes the entire diet, while nutrient indexes and nutrient profiling typically focuses on products, although some of them are applied to diet.

2.2.2 NUTRITION RECOMMENDATIONS/THE FINNISH NUTRITION RECOMMENDATIONS

Nordic countries have a long tradition of developing nutrition recommendations starting from 1980s: jointly negotiated Nordic recommendations have been updated every eight years (Becker et al., 2004; Fogelholm, 2013). The Finnish Nutrition Recommendations (National Nutrition Council, 2014) equals to the Nordic recommendations (Nordic Council of Ministers, 2014).

There are separate nutrition recommendations for adults, babies and children under school aged, school-aged children and teenagers, and elderly people in Finland. Nutrition recommendations for adults (hereafter the Finnish Nutrition Recommendations, FNR 2014) are dealt with in more detail in this section.

The FNR 2014 contains both NBDG and FBDG. The NBDG parts of the FNR 2014 include the same components as the Nordic Nutrient Recommendations, which are the following (adopted by Becker et al., 2004 with slight modification):

1) Recommended intake of fat, carbohydrates and protein as a percentage of total energy intake (E%).
2) Recommendations for dietary fibre.
3) Recommended intake of vitamins and minerals.
4) Reference values for energy intake.
5) Recommendations for salt intake.
6) Recommendations for alcohol consumption.

There are recommended daily intakes, daily reference values (DRVs), for ten vitamins (Table 1) and nine minerals (Table 2) on a mass-basis and for proteins, carbohydrates and fatty acids on a proportion-basis related to energy intake, i.e. as E% (Table 3), in the FNR 2014. In addition, there is a recommendation on DRV for fibre, which is 25-35 g. Most of these DRVs are utilized in Article III and the E% for proteins, carbohydrates and fat acids are utilized in Article II. In addition, there is a recommendation on the nutrient density of the entire diet for vitamins and minerals.

Table 1. Daily reference values (DRVs) for vitamins according to the FNR 2014 (The National Nutrition Council, 2014).

	Women 31 – 60 y	Men 31 – 60 y
Vit A, RAE	700	900
Vit D, µg	10	10
Vit E, α-TE	8	10
Thiamin (Vit B1), mg	1,1	1,3
Ribflavin (Vit B2), mg	1,2	1,5
Niacin, NE	14	18
Vit B6, mg	1,2	1,6
Folate (Vit B9), µg	300	300
Vit B12, µg	2	2
Vit C, mg	75	75

Table 2. Daily Reference Values (DRVs) for minerals according to the FNR 2014 (The National Nutrition Council, 2014).

	Women 31 – 60 y	Men 31 – 60 y
Calcium, mg	800	800
Phosphorus, mg	600	600
Potassium, g	3,5	3,1
Magnesium, mg	350	280
Iron, mg	9	15
Zinc, mg	9	7
Copper, mg	0,9	0,9
Iodine, µg	150	150
Selenium, µg	60	50

Table 3. Recommended proportion of proteins, fatty acids and carbohydrates of total energy intake, E%, for adults according to the FNR 2014 (National Nutrition Council, 2014).

	E%
Proteins	10-20
Fatty acids	25-40
Monounsaturated fatty acids	10-20
Polyunsaturated fatty acids	5-10
Saturated fatty acids	< 10
Carbohydrates	45-60
Added sugar	< 10

The FBDG parts of the FNR 2014 include a description of healthy diet and guidance on recommended food choices. In the FNR 2014, the description of a healthy diet utilizes the idea of the food pyramid by presenting a visualization of a "food triangle", as well as the plate model (for the visualizations, see National Nutrition Council 2014).

2.2.3 THE PLATE MODEL

The plate model is a visual communication tool to help consumers to put together a meal to match the recommendation of the NBDG. Different plate models have already existed for thirty years, as the first ones emerged in 1987 (Camelon et al., 1998).

The plate model has been utilized in individual counselling, group settings and public nutrition education. It is a powerful education tool because it helps the learner connect theory to practice, it provides relevance to day-to-day activities, and it makes it possible to involve the learner in the counselling occasion (Camelon et al., 1998).

There are actually several plate models which vary slightly from each other. For example, in the UK the plate model is called the eatwell plate, and it comprises starchy foods, non-dairy sources of protein, fruit and vegetables, milk and dairy food, and food and drinks high in fat and/or sugar, which all reserve their own sector of the plate (Harland et al., 2012).

According to the plate model presented in the FNR 2014, a half of the plate is for vegetables, which may be salads with vegetable oil-based dressings and/or warm vegetables. Another half should be divided into half proteins and half carbohydrates (starchy food). Protein sources may be fish, meat, eggs or plant-based protein-rich foods, such as legumes, nuts and seeds. Carbohydrate-rich food consists of potatoes, wholegrain pasta or other wholegrain side dishes. Skimmed milk or sour milk is recommended with the meal, and water as a "thirst-quencher". The plate model also includes wholegrain bread with vegetable oil spread, and berries or fruit as dessert.

2.2.4 NUTRIENT INDEXES

While nutrition recommendations are focused on public health, entire diet and individual nutrients, nutrient indexes, or nutrient profiling, are focused on products and selected key nutrients representing the nutrient density of a product by a single number (e.g. Azais-Braesco et al., 2006; Drewnowski, 2005). The basic idea of nutrient indexes is to provide aggregated, and thus easy-to-understand, information on the nutritional quality of food products to be used in a comparison (Drewnowski, 2005). They can be utilized in, e.g., nutrient counselling, nutrition education for consumers, and product labelling (Drewnowski, 2005).

Several different kinds of nutrient indexes have been developed across the world (e.g. Azais-Braesco et al., 2006; Drewnowski and Fulgoni, 2014). These are introduced in Article III, and the compatibility of nutrient indexes with the LCA is also discussed.

Although focusing on products, nutrient indexes should be in accordance with a healthy diet so that the ranking of products according to the nutrient index should reflect a healthy diet composition (Azais-Braesco et al. 2006; Darmon et al., 2009; Fulgoni et al., 2009). This has been used as a basis for validating nutrient indexes (Fulgoni et al., 2009). Examining the consistency between nutrient profiling and nutrient-based recommendations (Darmon et al., 2009) and testing nutrient indexes against expert opinion (Azais-Braesco et al. 2006; Scarborough et al., 2007) or against self-selected healthy diets (Arambepola et al., 2008; Volatier et al., 2007) have been the ways to validate nutrient indexes. In validation studies, nutrient indexes have been proven capable of discriminating more-healthy products from less-healthy products. From the nutrition science perspective, indexes which include both recommended and restricted nutrients perform better than indexes based solely on recommended nutrients (Fulgoni et al., 2009).

2.3 NUTRITION IN A CURRENT FOOD LIFE CYCLE ASSESSMENT AND DEVELOPMENT NEEDS

2.3.1 WHOLE DIET SCALE

The LCA of diets has been a focus area of food LCA in past five years. Before that there were just a couple of studies, of which the most important one was a study on the environmental impacts of healthier diets in Europe by Tuckert et al. (2011). It was one of the earliest studies that revealed that meat and dairy foods are among the highest contributors to environmental impacts of realized food consumption. It also revealed that food consumption is one of the three main consumption areas which contribute the most to the environmental impacts of consumption. There have also been a few Finnish studies which have revealed the same things in Finland (Risku-Norja et al., 2009; Seppälä et al., 2011; Virtanen et al., 2011).

Diet scale studies are based on varied designs. Diets may be based on realized food consumption (Donati et al., 2016; Hadjikakou, 2017; Hoolohan et al., 2013; Horgan et al., 2016; Sáez-Almendos et al., 2013; Sjörs et al., 2016; Soret et al_2014), or they can be modelled (Gephart et al., 2016; Horgan et al., 2016; Thaler et al., 2015; Ulaszewska et al., 2017), or a study may be comparative including both types of diets (Friel et al., 2013; Goldstein et al., 2016; Hendrie et al., 2014; Irz et al., 2016; Jensen et al., 2015; Meier et al., 2013; Pairotti et al., 2015; Pernollet et al., 2017; Röös et al., 2015; Saxe et al., 2012; Song et al., 2017; Temme et al., 2014; Tilman and Clark, 2014; van Dooren et al., 2014). Realized diets in studies usually present an average diet in a country, but sometimes the diets relate to some restricted group of people (Donati et al., 2016; Soret et al., 2014), or diets on a global scale (Tilman and Clark, 2014). Additionally, the timespan of food consumption varies from some days (Horgan et al., 2016) or one-week food basket (Donati et al., 2016; Friel et al., 2013; Sjörs et al., 2016; Ulaszewska et al., 2017) to a whole-year diet, however usually all of these are converted to an average diet per day (Goldstein et al., 2016; Hadjikakou, 2017; Hendrie et al., 2014; Meier et al., 2013; Pairotti et al., 2015; Röös et al., 2015; Sáez-Almendos et al., 2013; Saxe et al., 2012; Song et al., 2017; Temme et al., 2014; Thaler et al., 2015; van Dooren et al., 2014). In recent years, the modelled diets in the studies are most often based on an argued view of a research group (Pairotti et al., 2015; Röös et al., 2015; Saxe et al., 2012; Song et al., 2017; van Dooren et al., 2014), or the model diets developed in earlier projects (Ulaszewska et al., 2017), with attempts to ensure the nutritional quality of the diets by adopting nutritional recommendations. However, according to the review by Hallström et al. (2015), methods for scenario development are one of the main methodological aspects which have a major influence on the quality and results of dietary scenario studies. Additionally, FUs vary between the studies (Hallström et al. 2015): the results may be expressed, for example, per diet per person/year, month, week or day (e.g. Donati et al., 2016; Saxe et al., 2012; Soret at al.,2014; Pairotti et al., 2015), or per energy unit (J or kcal) per day (Röös et al., 2015). For some studies, the compared diets are adjusted to include a certain amount of energy or protein (e.g. Saxe et al., 2012). None of these methodological choices are standardised, and different choices have their strengths and weaknesses.

Aside from varied nutritional quality, it is notable that system boundaries of product systems in diet LCAs vary (Hallström et al., 2015). Environmental modelling for foods included in diets has usually been limited to include life cycle phases until the farm gate, but some of the studies include at least some post-farm phases or aspects, such as post-farm losses in the study by Goldstein et al. (2016). Furthermore, most of the studies follow an attributional approach to the LCA, but there are some consequential LCA studies (Goldstein et al., 2016). Even impact categories vary: the climate impact is the most often assessed impact category, but some studies include a much broader suite of impact categories (e.g. Goldstein et al., 2016; Pernollet et al., 2017; Tucker et al., 2011). These methodological choices may significantly affect the results and the conclusions, as Goldstein et al. (2016) and Hallström et al. (2015) have also argued.

Incomplete consideration of nutrition can be seen as one of the main weaknesses of the LCA application on a dietary scale (Perignon et al, 2016). As Perignon et al. (2016) express in their review article: "…nutritional adequacy was rarely or only partially assessed, thereby compromising the assessment of diet sustainability". While in their early stages, dietary scale studies examined the whole diet representing a nutritional entity without assessing nutritional quality properly; nowadays most of the studies assess nutritional quality separately, alongside the assessment of environmental impacts (e.g. Tilman and Clark, 2014). More recently, the nutritional and environmental quality of diets have been optimized against each other in order to form a sustainable diet (Gephart et al., 2016; Song et al., 2017; Tyszler et al., 2014) or even an individually optimized diet (Horgan et al., 2016) so that not only the climate impact of diets but also changes to the current individual diets are minimized. Some of the studies optimize diets also in relation to the affordability of food (Donati et al., 2016; Hoolohan et al., 2013; Irz et al., 2016; Jensen et al., 2015).

In summary, according to recent review studies, dietary change towards a diet that would contain less animal-based products can, in general, significantly reduce climate impact and land use caused by food consumption compared to the western style diet (Hallström et al., 2015; Perignon et al., 2016). However, there is still a need for further research on the environmental impacts related to foods to replace or complement meat and other animal-based products in the context of diet (Hallström et al., 2015; Perignon et al., 2016). Furthermore, the total energy intake is an important factor for reducing diet-related greenhouse gas emissions (Perignon et al., 2016). Hallström et al. (2015) also highlight a need for improved knowledge concerning uncertainty in dietary scale studies, and research into the effect of possible dietary changes in different groups of populations and geographical locations.

2.3.2 A MEAL SCALE

In addition to Article II there are only few studies reported in scientific journals on the LCA of meals (Calderon et al., 2010; Carlsson-Kanyama, 1998; Davis and Sonesson, 2008; Davis et al., 2010; Hansen et al., 2017; Rivera et al., 2014, Rivera and Azapagic, 2015; Sanfilippo et al., 2012; Sonesson et al., 2005). Most of these assess climate impact or climate impact and potential eutrophication. Davis et al. (2010), and Sanfilippo et al. (2012) however assess a wider range of impact categories. Hansen et al. (2017) also assess the production of food waste in different production chains.

The rationale for assessing the environmental impacts of the meals in the above mention studies lies in an evaluation of alternatives. Meals, however, also have fundamentally different features compared to individual foods, which makes carrying out an LCA for them particularly interesting. Meals consist of at least a couple or a number individual foods or ingredients, and thus the LCA of a meal lies somewhere between the LCA of individual products (excluding convenience foods) and the LCA of a diet. Furthermore, individual foods are not quite independent from the nutrition point of view as they have complementary roles in diets: some groups of products serve mainly as sources of protein, while others are sources of carbohydrates or fatty acids (and in the mean time they are all sources of energy and a variety of other nutrients). However, a meal typically consists of individual foods from these different food groups. Thus, by carrying out an LCA of meals, it is possible to evaluate replacements for meat with plant-based proteins, for example, taken the wider context of eating than individual foods into account without assessing the overall diet with hundreds of products. This provides a more realistic insight than considering individual foods because a meal combines products from different product groups (with their complementary roles in diets). Furthermore, the size of servings of different foods will be better taken into account in the context of a meal. Additionally, nutrition education for consumers leans strongly on the plate-model alongside the food-pyramid approach (see more in detail in section 2.2.3.

LCA studies on meals typically compare different kinds of meals (Carlsson-Kanyama, 1998; Davis et al., 2010; Davis and Sonesson, 2008; Hansen et al., 2017; Rivera et al., 2014; Sanfilippo et al., 2012; Sonesson et al., 2005). A protein part of a meal is often a determinant for the comparison, i.e. the comparison is between protein sources in the context of meal (Article II; Carlsson-Kanyama, 1998; Davis et al., 2010; Sanfilippo et al., 2012). Another basis for comparison is the place where the meal is prepared, i.e. home-made vs. ready foods (Article II; Davis and Sonesson, 2008; Hansen et al., 2017; Rivera et al., 2014; Sonesson et al., 2005). Rivera and Azapagic (2015) also added costs to the assessment. One branch of LCA studies on meals are those of canteen or school meals (Article II; Sanfilippo et al., 2012).

The meal approach is very diverse and complex because meal composition and the FUs vary greatly between the studies. Most attention has been paid to the comparison of the main dishes of home-made and ready meals (Davis et al., 2010; Rivera and Azapagic, 2015; Sonesson et al., 2005) or between different canteen meals (Sanfilippo et al., 2012). In these studies, other parts of the meal are included as a fixed addition or are totally excluded from the comparison. Our work (Article II) makes a difference by also comparing other parts of the meal, i.e. salad or vegetable additions, bread and drinks. These are included in a nutritionally balanced meal according to the plate model (National Nutrition Council, 2014).

The works by Davis and Sonesson (2008) and Calderon et al. (2010) did not aim at comparing meals, but were more typically case studies with the aim to identify hotspots of environmental impacts within the meals.

The nutritional quality of meals has not, in general, been identified very precisely in the studies: typically meals to be compared in studies are alternatives from the perspective of the consumer without detailed comparability in nutritional quality (Calderon et al., 2010; Hansen et al., 2017; Rivera et al., 2014, Rivera and Azapagic, 2015; Sanfilippo et al., 2012; Sonesson et al., 2005). However, in the work by Carlsson-Kanyama (1998) the meals have equal energy and protein content, and in a study of Davis and Sonesson (2008), Davis et al. (2010) and in our own study (the Article II) meals have been standardised based on the plate model and general nutrition recommendation on the division of energy intake from fats, protein and carbohydrates, and the total energy content of a meal.

It is challenging to draw conclusions based on results from studies on the meal scale because of the diversity of applications and narrow range of different meals. For example, the ranking order between home-made and ready-to-eat meals differs between studies: Rivera et al. (2015) and Hanssen et al. (2017) found higher climate impacts for ready-to-eat meals than for home-made meals in contrast to Sonesson et al. (2005). However, all the studies which compared animal-based meals to vegetable-based meals resulted in higher environmental impacts for animal-based meals than vegetable-based meals (Calderon et al. 2010; Carsson-Canyama, 1998; Davis et al, 2010; Sanfilippa et al., 2012), but to different extents. Davis et al. (2010) also paid attention to energy-efficiency in manufacturing vegetable-based ingredients to reduce the climate impact of food consumption even further.

2.3.3 A PRODUCT SCALE

Animal-based foods have, in general, been proven to cause more environmental impact per kilo than plant-based products, even considering consumption rates, bio-waste, human excretion and related wastewater (Notarnicola et al., 2017b). The foods, however, have different nutrient compositions and nutritional functions within the diet. Animal-based products are typically rich in proteins and some other nutrients and their amino acid composition is better than protein-rich plant-based products. From the point of view of nutrition, these facts should be taken into account in food LCA particularly because comparison between products should be based on similar functions of the products to which impacts are allocated. Issues of varied nutritional quality also relate to other product groups than protein sources, for example vegetables, fruits and berries due to the varied composition of secondary metabolites (Schreiner, 2005), and products rich in fats due to the varied composition of fatty acids (Dubois et al., 2007).

Current food LCA practice for products ignores these facts to a large extent. There are, however, some more or less tentative approaches and studies attempting to find methods to include nutrition in the LCA of a food product, and to compare products based on it (Doran-Browne et al., 2015; Masset et al., 2014; Schau and Fet, 2008; Sonesson et al., 2017; Stylianou et al., 2016).

Approaches of product scale studies can be divided to 1) those using midpoint impact indicators (Doran-Browne et al., 2015; Masset et al., 2014; Schau and Fet, 2008; Sonesson et al., 2017), and 2) those using endpoint impact indicators (Stylianou et al., 2016). The midpoint indicators refer to the potential environmental impacts, such as climate impact, eutrophication, acidification, eco-toxicity, etc., while the endpoint indicators refer to damage in an environment to be protected, in the case of nutrition this is human wellbeing.

To my knowledge, Stylianou et al. (2016) are the only ones who have introduced an endpoint impact indicator concerning damage to human health which includes nutrients. Their approach compares epidemiologybased nutritional impacts and benefits linked to milk intake with selected environmental impacts, such as global warming and particulate matter, carried over to affect human health. They also assessed the impacts of two dietary scenarios in which milk substitutes other food items. What is the most important is that they propose a framework for harmonizing nutritional and environmental effects over food life cycles, called Combined Nutritional and Environmental LCA (CONE-LCA). In this work, they link nutritional aspects directly to the endpoint impact indicator of damage to human health using Disability Adjusted Life Years (DALYs) as an indicator unit. Additionally, the effects of climate change and particulate matter on human health are expressed in DALYs. Thus the sources of impacts can be compared and trade-offs between nutrition and the environmental human health burden can be assessed and identified. It is notable that this approach focuses on both positive and negative health outcomes directly at the level of the endpoint indicator, and they did not link nutrition to the midpoint environmental indicators at all. Based on this approach, the main result of their study indicated that: "…adding one serving of milk to the current average diet could result in a health benefit for American adults, assuming that existing foods associated with substantial health benefits are not substituted, such as fruits and vegetables".

The approaches using the midpoint indicators can be further divided to 1a) those using nutritional quality as FUs (Doran-Browne et al., 2015; Schau and Fet, 2008; Sonesson et al., 2017), 1b) those linking nutrition as a separate score to the assessment (Drewnowski, 2015; Masset et al., 2014), and 1c) those using both the above mentioned approaches. The target of 1b and 1c particularly is to determine sustainable food products, while 1a and 2 seek to link nutrition to impact assessments more theoretically.

These approaches include either individual nutrients (Doran-Browne et al., 2015; Sonesson et al., 2017) or several nutrients (Doran-Browne et al., 2015; Drewnowski, 2015; Masset et al., 2014; Schau and Fet, 2008; Stylianou et al., 2016) in the consideration at the same time. Protein is most commonly used individual nutrient as an FU in food LCA studies. However, Tessari et al. (2016) and Sonesson et al. (2017) go further and use the Daily recommended intake (DRI) of essential amino acids (EAA) as an FU. Nutrient indexes (see section 1.2.4.) are often utilized when several nutrients are considered at the same time. Usually, general nutrient indexes have been utilized instead of product group specific nutrient indexes; to my knowledge, Article III is the only one dealing with a product group specific nutrient index.

Masset et al. (2014) concluded their findings from a comparison of energy- and mass-based FUs in relation to nutrient quality indicators and food prices: "In conclusion, it appeared that neither the 100 g nor the 100 kcal functional unit would be 'best' to identify foods more likely to be included in sustainable dietary patterns. An alternative functional unit integrating foods' nutritional quality and possibly other sustainability criteria may represent a more adequate option. The study showed that the choice of functional unit is crucial since it can lead to very different conclusions regarding individual foods."

2.4 THE APPROACH OF THIS STUDY

The dissertation builds the theoretical basis for linking nutrition to the assessment of the environmental impacts of food and introduces corresponding methodological solutions and potential tools. I have applied and developed a methodology of LCA, which is one of the most used life-cycle-based assessment methodologies, to consider nutrition alongside environmental impacts on product and meal scales, building on both nutritional knowledge and LCA know-how.

The dissertation also links to nutrition guideline approaches: Article II mostly utilizes visual nutrient recommendations (the plate model), and quantitative nutrition recommendations (the Finnish Nutrition Recommendations) applied in an everyday food production-consumption context and its related decision framework; while Article III utilizes an advanced quantitative approach (nutrient indexes), and also quantitative nutrition recommendations (the Finnish Nutrition Recommendations). Thus the nutrition recommendations, particularly the Finnish Nutrition Recommendations (National Nutrition Council, 2014), the plate model and the nutrient indexes are the most important tools in respect to this dissertation.

I have focused on climate impact (global warming potential, GWP) as an impact category for the LCA in this dissertation because the impact assessment methodology for climate impact is the most established one and data on the climate impact of various foods is widely available. Additionally, the methods and tools developed in this dissertation are primarily not dependent on the impact category. In Article III, I focused on protein sources as a target product group because protein is a crucially important nutrient from the point of view both nutrition and environment/climate. Additionally, the data on proteins sources in respect to these aspects is widely available. The theoretical basis of the methodologies developed in this dissertation is applicable for other product groups too.

This dissertation links to Contento's (2008) first component of education. It aims to help to increase awareness of the nutritional and environmental impacts of food. The methodologies developed and demonstrated in the dissertation are practically-oriented so they provide tools, or the basis for tools, for consumer communication about the sustainability of food.

3 OBJECTIVES OF THE STUDY

This dissertation aims at developing and analyzing ways to link nutritional aspects into LCA of the environmental impacts of food. Its focus is in a product and portion level consideration as a primary consumer choice operates in that context. In product level, product-group-specific approach is emphasized, and so called protein source foods are highlighted as an example of a product group.

Hypothesis of the dissertation is:

> Nutrition can be taken into account in the food LCA on the product and the portion scales so that relevant additional information can be achieved compared to the current LCA practice.

To prove the hypothesis, the dissertation answers the questions:

1. How can nutrition be taken into account by FUs in product and meal level LCAs? What kinds of questions can these approaches answer? What kind of information can the approaches provide?
2. What preconditions and challenges does an assessment have when these approaches are applied?
3. Do different approaches result in different outcomes and interpretation of the environmental/climate impact of food products?

4 MATERIALS AND METHODS

This section gives an overview of the materials and methods used, developed and tested in this dissertation. The materials and methods are described in more detail in the original publications (Articles I-III).

The schematic structure of the dissertation is outlined in Figure 3. Articles I and II represent a production-chain-specific LCA, which meets a high standard of data quality in relation to particular production chain and meets the requirements for, for example, product labelling. Article II develops a method for meals and Article III develops a method for individual products. Articles I and II also provide LCA results for products and meals based on data collected in the studies, whereas Article III includes a test assessment based on environmental data from previous studies, a database (Ecoinvent) and literature, nutritional data from a database (THL, 2017) and the method developed in Article III. Thus it provides merely test results rather than final results for certain products. I answered the research questions based on all of this information.

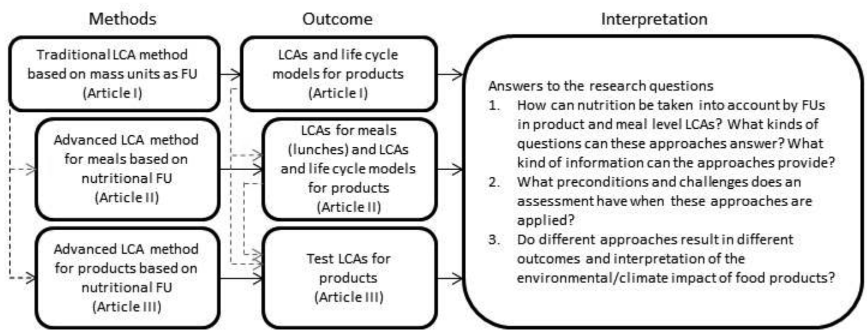

Figure 3. The schematic structure of the dissertation.

The research consists essentially of methodological development. This was stressed in Article II and particularly in Article III. I followed a methodological development process consisting of a review of methods, testing, creation of new methods, interpretation and correction, not forgetting to learn from the blind review process for Articles and other feedback. The workflow for the methodological development is presented in Figure 4.

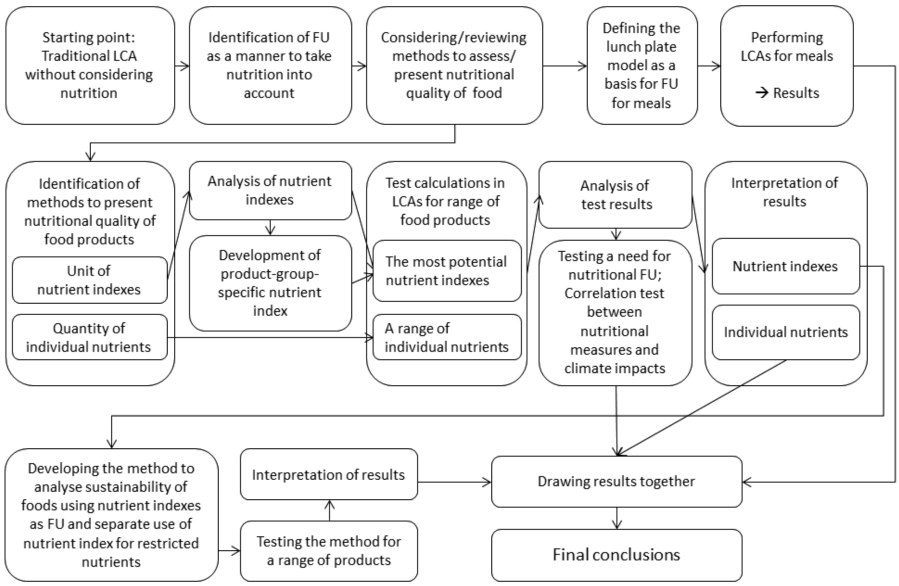

Figure 4. The workflow of methodological development in the dissertation.

4.1 SELECTING NUTRIENT INDEXES

I used literature on nutrient indexes as a source for indicators for nutrient quality of food products. The literature consisted of 17 articles and reports in which different nutrient indexes were introduced and analysed (Table 4). I reviewed and tested 13 different nutrient indexes from the literature, proceeding to a preliminary analysis of 7 indexes and test calculation based on these indexes in addition to one index developed in our study (this part of the work is partly unpublished, partly published in Saarinen (2012)). On the basis of these steps, I chose one nutrient index based on beneficial nutrients, and two nutrient indexes based on harmful nutrients from the literature, and one product-specific nutrient index created in our study to be included in the final analysis and test calculations presented in Article III. A review of nutrient indexes and preliminary analysis of them included indexes for all kinds of products. The focus on protein sources in Article III allowed me to evaluate a product-group-specific index. The chosen nutrient indexes are described in sections 4.4.2 and 4.4.4.

Table 4. Literature on nutrient indexes reviewed in the dissertation.

Source	Contribution	Indexes included
Azais-Braesco et al. 2006	A comparison of existing nutrient indexes (including indexes based on the relation between beneficial nutrients and calories)	Calories-for-nutrient (CFN) The Ratio of recommended to restricted (RRR) Nutritious Food Index (NFI) The Nutrient Profile
Darmon et al. 2005; 2009	An introductory of nutrient index for vegetables and fruits, comparison to cost	Nutrient Adequacy ScoreScore of nutritional adequacy of individual foods (SAIN) LIM system
Drewnowski 2005	Commentary on nutrient indexes; discussion on the concept of nutritious food, comparison of existing nutrient indexes (including indexes based on the relation between beneficial nutrients and calories)	Nutritional Quality Index (NQI) The ratio of recommended to restricted (RRR) The Padberg index Calories-for-nutrient (CFN) Naturally nutrient rich (NNR)
Drewnowski and Fulgoni 2008	Discussion on criteria for development process of nutrient index, comparison of different nutrient indexes	Nutritional Quality Index (NQI) Calories for Nutrient (CFN) Nutritious Food Index (NFI) Ratio of recommended to restricted (RRR) Naturally Nutrient Rich (NNR) Nutrient Adequacy Ratio (NARn) SAIN16 SAIN23 Nutrient Rich Food (NRFn-3)
Drewnowski 2010	Identifying healthy, affordable foods and food groups.	Nutrient Rich Food (NR9) LIM3 Nutrient Rich Food (NRF9-3)
Drewnowski and Fulgoni 2014	Validation of nutrient indexes	Nutrient Rich Food (NR9) LIM3 Nutrient Rich Food (NRF9-3)
Fulgoni et al. 2009	Validation process for nutrient indexes, analysis of Nutrient Rich Food family of indexes	LIM (added sugar) LIMt (total sugar) Nutrient Rich Food (NRF6-3) Nutrient Rich Food (NRF9-3) Nutrient Rich Food (NRF11-3) Nutrient Rich Food (NRF15-3)
Labouze et al. 2007a, 2007b	Introduction of nutrient profiling system based on a nutrient index and criteria for classifying foods	TheFoodProfiler
Lachance and Fisher 1986	Introduces nutrient index based on relation between energy and beneficial nutrients	Calories for Nutrient (CFN)
Maillot et al. 2007	Introduces nutrient index to be used on the food group scale, analyses of food groups also in terms of contribution to diet energy and cost	Nutrient Density Score (NDS23) LIM3
Miller et al. 2009	Guiding principles for the development and implementation of nutrient indexes	FSAWXYfm LIM NRF9.3
Rayner et al. 2004; 2005	Introduction of nutrient index	WXYfm SSCg3d
Scheidt and Daniel 2004	Introduction of a nutrient index based on ratio of beneficial and limited nutrients	Ratio of Recommended to Restricted Foods (RRR)
Smedman et al. 2011	Introduction of weighted nutrient index for beverages (used in calculating nutrients quality in relation of GWP)	Nutrient Density (ND)
Zelman and Kennedy 2005	Introduction of nutrient index	Naturally Nutrient Rich (NNR15)

4.2 CASE-PRODUCTS

I used LCAs for 66 products in this dissertation (Table 5): 7 of these were included in Article I, 27 foods were included in 29 lunch plates analysed in Article II and 30 foods were analysed by the nutrient index approach in Article III. An LCA for broiler fillet was used in all Articles, but for different forms of product. LCA for rainbow trout (Silvenius et al., 2017) was utilised in Articles II and III, and an LCA for cheese in Articles I and III. The methodological choices for these LCAs (except for the FU, which is the subject of development in this dissertation) are presented in section 4.3.

The products included in Article I represented early LCAs done by Luke's (formerly MTT) research group before I participated in the group. The preliminary results for these LCAs were included in the article by Nissinen et al. (2007) which developed a communication tool for consumer education. In Article I, we reviewed methodological development and analysed the comparability of LCA results within this group of food products. The products of these LCA studies were initially selected so that they represented varied product groups from greenhouse vegetables (cucumber) to meat products (broiler fillet). These products, corresponding life cycle models and LCA results provided a solid basis for later research according to the lunch plate and nutrient index approaches, although more extensive data was also needed. Lately one of these LCAs, namely LCA for broiler, has been published more in detail by Katajajuuri et al. (2014).

In Article II, products were included in meals which were adjusted to the lunch plate model, i.e. products were listed as raw materials for meals. We designed the meals so that they would potentially provide a wide range of environmental impacts assessed in the study. In addition, a comparison between home-made and ready-to-eat meals had to be possible. Hence, for example, minced meat casserole with salad, drink and bread was selected to be one of the meals and it was analysed as home-made and ready-to-eat portions. LCAs for products (i.e. raw materials for meals) were partly taken from previous studies and literature but mostly from the modelling done in our study. LCAs based on the modelling during the study have also been reported by Virtanen et al. (2011) and in the conference papers by Saarinen et al. (2012) and Usva et al. (2012). My role in the study was mostly in developing a relevant FU, coordinating the designing of lunches and in interpreting the results based on this novel FU (standardised lunch), but I was also involved in the life cycle modelling of the products included in the lunches.

In Article III, I limited the assessment to protein sources. Protein is one of the key nutrients for health and it is particularly important from the point of view of environmental impacts given that animal-based products, which are rich in protein and other nutrients, often have much higher environmental impacts per kilo than other foods. Thus it is interesting to analyse how an inclusion of nutrition affects the comparison between protein sources. In this dissertation, methodological development however was the most crucial issue and thus the results from the test calculation should be interpreted cautiously. The selection of the products covered plant-based products, freshwater fish, sea food, eggs and meat. I used a wide range of products in obtaining exhaustive test results. This helped to draw conclusions about the capabilities of the nutrient index approach.

Table 5. Products for which LCAs were made to be utilised in this dissertation.

Products in Article I		**Products in Article II**				**Products in Article III**			
1	Cucumber	1	Broad bean	15	Wheat	1	Hemp seed	16	Tuna fish, canned
2	Oat flakes	2	Parsnip	16	Chinese cabbage	2	Peanut	17	Pollock, frozen, fried
3	Beer	3	Potato	17	Swedish turnip	3	Hazelnut	18	Shrimp
4	Potato flour	4	Carrot	18	Rise	4	Walnut	19	Spiced/salted herring
5	Broiler fillet	5	Beetroot	19	Soybean	5	Cashew	20	Egg, boiled
6	Cheese	6	Onion	20	Turnip rape	6	Peas, dry, cooked	21	Beef, fried
7	Gratinated potato	7	Cucumber	21	Hay	7	Soybean, cooked	22	Pork slices, fried
		8	Lettuce	22	Beef	8	Kidney bean, cooked	23	Reindeer, roasted
		9	Tomato	23	Pork	9	Broad bean, cooked	24	Reindeer, roasted
		10	Strawberry	24	Milk	10	Rainbow trout, roasted	25	Grilled sausage, meaty
		11	Blackcurrant	25	Eggs	11	Baltic herring fillet, fried	26	Broiler, slices, fried
		12	Oats	26	Broiler fillet	12	Pike, fried with butter	27	Broiler, breast, roasted with skin
		13	Barley	27	Rainbow trout fillet	13	Perch, fried with butter	28	Mutton, low-fat, cooked
		14	Rye			14	Vendace, fried	29	Cheese, Emmental, fat 27-30 %
						15	Whitefish, fried with butter	30	Cheese, Edam, fat 24-27 %

4.3 THE LIFE CYCLE ASSESSMENTS

An attributional approach was applied in the LCAs for the products instead of consequential approach. Attributional LCA is a particularly usable approach for providing product-specific information for consumers. This choice of approach, however, does not restrict the use of the method developed in the dissertation, per se, in consequential LCAs. Product systems included phases from input production for primary production (agriculture), primary production, manufacturing, logistics, packages and trade, and preparation at home or in a catering kitchen, with the exception of products assessed in Article I for which preparation phase was not included. Waste in the production phases was included, but leftovers from consumers were excluded except from the lunch plates in a school canteen (Article II). System boundaries for lunch plates in the school canteen also included energy use in the dining room, because the room is there just for eating purpose. The system boundaries are described in more detail in Articles I-III and by Katajajuuri et al. (2007), Saarinen et al. (2012), Silvenius et al. (2017), Usva et al. (2012) and Virtanen et al. (2011).

Data for LCA modelling consisted of both primary data from the production chain and relevant statistics and secondary data from the literature and LCA database Ecoinvent. Data for LCAs based on modelling carried out in Luke's LCA research group's studies is also described in Articles I-III and by Katajajuuri et al. (2007), Saarinen et al. (2012), Silvenius et al. (2017), Usva et al. (2012) and Virtanen et al. (2011). The extensive use of primary data in the LCAs utilised in the dissertation was possible because the studies were conducted in cooperation with Finnish food companies (particularly Article I and II, but in Article III only regarding Edam cheese). In Articles II and III, data on primary production represented average Finnish production for domestic products. This was mostly from un-public Cultivation Database maintained by ProAgria Rural Advisory Services. The data sources varied more between products in Article I than between products in Articles II and III. Article I describes the methodological development of Finnish food LCA, and the data quality is one of the areas developed. In general, a lot of effort has been put into obtaining as high-quality data as possible.

It is, however, important to notice that reasonable data quality requirements should be in accordance with the goal and scope of the study. In Articles I-III, the scope and goal varied, and accordingly the data quality requirements varied slightly. Data for the products in Article I was taken completely, and in Article II very broadly, from Finnish production chains, while in Article III there were more imported products. Data on imported products were from the Ecoinvent database and from the literature. This may cause some inconsistency particularly regarding comparison between domestic and imported food, but it is supposed that the data used for both domestic and imported foods is quite descriptive for those food systems. The biggest inconsistency for domestic foods relates to cheeses: the GWP and eutrophication data for Emmental cheese was taken from early studies (Article I) and the values for Edam cheese (Article III) were from updated calculations with different allocations between cheese and whey resulting a much lighter burden for cheese, which reflects changes in practices in the production of dairy products. Different data sources for domestic and imported foods result in restricted applicability of the results from the test calculations; which are more applicable to food provision in Finland than abroad. But this possible inconsistency of data and restricted applicability of results was accepted because this dissertation focuses on the methodological development of FU, and not a comparison between products.

I used the climate impact (global warming potential, GWP) as an impact category in this dissertation in the development and testing of the method for including nutrition in a food LCA. Initially the assessment for the lunch plates also included an assessment of potential eutrophication and the assessments in Article I as well as some other impact categories. The assessment of a broader set of impacts would have been beneficial to drawing more solid conclusions on a ranking order of products based on test calculations and would have been in accordance with the guidance in LCA standards (ISO 14000, 2006; ISO 14044, 2006). On other hand, a broader set of indicators might have complicated drawing conclusions on the usability of the methods due to multiple materials to be taken into account in parallel. In future research, it will indeed be necessary to also apply the methods to an assessment of other impact categories.

4.4 FUNCTIONAL UNITS

A functional unit (FU) was used as a main methodological means to deal with the nutritional quality of products in the food LCA in this dissertation. Currently widely used mass based FUs potentially misrepresent the environmental impacts of products in relation to other food products because the FUs do not reflect the most important functional dimension, the nutritional function. I developed novel nutritional FUs in this dissertation, evaluated their usability and made test calculations based on them. A comparison of relative LCA results per mass based FUs and nutritional FUs was one of the subject matters of evaluation. In this comparison I utilized a concept of sustainability, which includes both environmental and nutritional dimensions.

Types of FUs used in this dissertation were:
1. FU based on mass or volume of the food itself.
2. FU based on quantity of individual nutrients.
3. Unit of nutrient index for a product as FU.
4. Standardised lunch as FU.

The use of the FUs in Articles I-III is illustrated in Figure 4. A mass or volume-based FU for the food itself was used in Article I in the final results for case-products and in Article II in the intermediate results for the raw-materials for lunches. We introduced and used a standardised lunch as an FU in Article II. In Article III, we used FUs based on the quantity of individual nutrients and developed and tested nutrient indexes for a product as FUs.

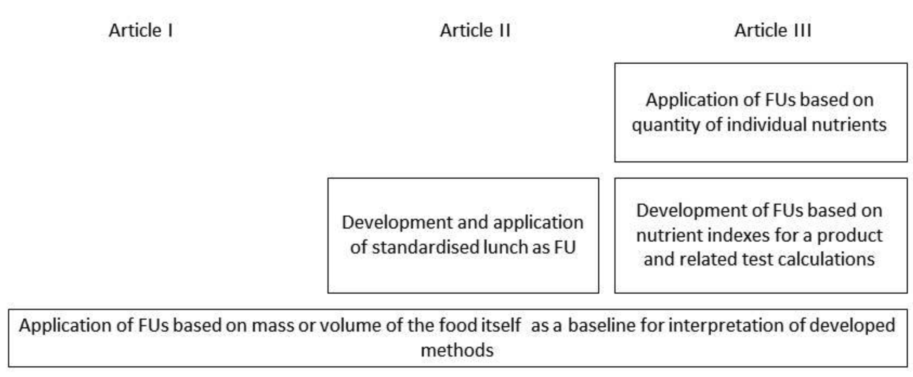

Figure 4. The use of different FUs in Articles I-III.

4.4.1 FUNCTIONAL UNITS BASED ON STANDARDISED LUNCH

A portion level FU was designed according to the model portion of the recommended lunch plate (National Nutrition Council, 2014) and is called a standardised lunch in this dissertation. Also, an actualised school lunch was applied as an FU in Article II, but this is not compatible with the standardised lunch due to different and varied actual portion sizes. These depended on the actual consumption by pupils. Thus, the school lunch is not applied and discussed further in this dissertation.

Lunches were comprised of the main course (with a side dish if applicable), salad, a drink and bread according to the plate model (the National Nutrition Council, 2014). Each lunch was constructed carefully so that they fulfilled the definition of the FU. The basic attributes are described in Table 6 (Article II, Table 1).

It is notable that due to the starting points, i.e. following the lunch plate model with nutritional standardisation based on nutrient recommendations, as well as focusing on typical foods and their typical portions as far as possible, the actual food portions and energy content of lunches slightly varied (Table 6). This is in accordance with consumer decision making situations when people choose their lunches. Neither are the current nutrient recommendations pedantic in their energy intake recommendation, but they do take physical activity into account (the National Nutrition Council, 2004, 2014). Thus, in this dissertation a standardised lunch is the FU and the amount of foods which constitute a lunch and its energy and nutrient content represent reference flows (RFs) fulfilling the FU in question.

Another FU could have been an energy-equalised lunch, for example. In that case, the energy content of the lunches would have been equalised to be exactly one third of the daily recommended intake for energy, or the FU could have been defined as 1, 10 or 100 kilocalories or joules, for example. The equalisation could also been based on protein or other nutrients. This, however, would have led to a more diverse approach and away from the actual every day situation of consumer decision-making and it was not applied in this dissertation.

Table 6. Food portions used as functional units (FU). The lunch plate is a model portion based on nutrient recommendations (The National Nutrition Council, 2014), and their nutritional functions.

Portions used as FU	General structure of the lunch servings	Total energy content[a], kcal	Share of energy intake from[b]		
			Protein	Carbo-hydrate	Fat
Standardised lunch	According to the general lunch plate model	Home-made lunches: 728-739	16-23%	49-57%	25-35%
		Ready-to-eat lunches: 728-748	12-18%	48-63%	32-35%
An actual school lunch	According to the general lunch plate model	558-731	11-29%	44-57%	18-40%

a The target energy content was 740 kcal according to the Finnish Nutrition Recommendations (The National Nutrition Council, 2005).

b The target energy intake from protein was 10-15%, carbohydrate 50-60% and fat 25-35% (The National Nutrition Council, 2005).

4.4.2 CORRELATION TEST FOR FUNCTIONAL UNITS AT PRODUCT LEVEL

Pearson's product-moment correlation test was used to determine the need for a separate product level nutritional FU (Article III). The aim was to examine whether the amount of some nutrient or a nutrient index could be used as an indicator of the climate impact of foods based on the fact that the content of the nutrient, for example protein, would be a strong determinant of the climate impact. In this case a food rich in this nutrient would also be climate-friendly or the opposite. The test was conducted in the statistical software R version 3.0.2 (2013-9-25).

In the statistical test, an association between climate impact for protein sources (section 3.2, two last columns in Table 5) and amount of individual nutrients including these products or six different nutrient index scores for those products was evaluated. Individual nutrients tested are listed in Table 7 (section 4.4.3). Nutrient indexes tested were two nutrient indexes including recommended nutrients, NR9 and $FNI_{prot}7$ (see section 4.4.4), two nutrient indexes including restricted nutrients LIM2 and LIM3 (see section 4.5) and two nutrient indexes including not only recommended but also restricted nutrients, NRF9-3 (Fulgoni et al. 2009) and $FNI_{prot}7$-2 (Article III). I abandoned NRF9-3 and $FNI_{prot}7$-2 from further development of a product level nutritional FU, because they confer misleading results (Article III, see also Saarinen, 2012), but the correlation between them and climate impact would still had been possible and thus I included them into the correlation test.

NFF9-3 includes nine recommended nutrients, protein and fibre, Ca, Fe, Mg, K, Vit A, C and E, and three nutrients to be limited, Na, Saturated fatty acids (SAFA) and added sugar. The formula is:

(3) $NRF9-3 = \sum_{i=1-9} \frac{nutrienti}{DRIi} \times 100/9 - \sum_{i=1-3} \frac{nutrienti}{DAi} \times 100/3$

(Fulgoni et al. 2009)

$FNI_{prot}7$-2 was formed in this study, using $FNI_{prot}7$ as the base and following the calculation principles of NRF9-3, but varying in the amount and a selection of nutrients. It includes protein, MUFA, PUFA, Ca, Fe, riboflavin (B2) and Folic acid (B9) as recommended nutrients and only Na and SAFA as nutrients to be limited because added sugar is not important for protein sources. The formula is:

(4) $FNIprot7-2 = \sum_{i=1-7} \frac{nutrienti}{DRIi} \times 100/7 - \sum_{i=1-2} \frac{nutrienti}{DAi} \times 100/2$

(Article III)

In (3) and (4), $nutrient_i$ means the amount of nutrient i in 100g of a food product, DRI_i is the daily recommendation for the intake of nutrient i and DA_i is the daily allowance for the intake of nutrient i.

4.4.3 FUNCTIONAL UNIT BASED ON QUANTITY OF INDIVIDUAL NUTRIENTS

Individual nutrients and the corresponding FUs (Article III) are presented in Table 7. We selected these nutrients because the intake of them is strongly linked to protein source foods on a dietary scale, and thus typical protein source foods can be critical in respect to the intake of these nutrients. If a typical protein source food, for example red meat, would be substituted by other products, for example for environmental reasons, a change in the intake of these nutrients should also be taken into account. The nutrient composition for foods was taken from the nutrient composition database – Fineli®, maintained by the Nutrition Unit of the National Institute for Health and Welfare (THL, 2017).

A reference amount (RA) for each nutrient, i.e. an amount of a product fulfilling DRI of the nutrient, was used alongside these FUs. By using these two measures together it can be assessed whether a food product is a good and eco-efficient source of the nutrient.

Table 7. Individual nutrients and corresponding functional units (FUs) used in the study (Article III).

Item	Unit
Protein	g
PUFA (Polyunsaturated fatty acids)	g
MUFA cis (Monounsaturated fatty acids)	g
Fe	mg
Ca	mg
Folate	µg
B2	µg
B12	mg
Se	µg
Zn	mg

4.4.4 FUNCTIONAL UNIT BASED ON NUTRIENT INDEXES FOR A PRODUCT

The product level nutrient indexes used as FUs were NR9 (Nutrient Rich Food) and $FNI_{prot}7$ (Finnish Nutrient Index for protein sources) (Article III). Basic information about these indexes is presented in Table 8 and their formulas are:

(1) $NR9 = \sum_{i=1-9} \frac{nutrienti}{DRIi} \times 100/9$ (Fulgoni et al., 2009)

(2) $FNIprot7 = \sum_{i=1-7} \frac{nutrienti}{DRIi} \times 100/7$ (Article III)

In (1) and (2) $nutrient_i$ means the amount of nutrient i in 100g of a food product, and DRI_i is the daily recommendation for intake of nutrient i. Both nutrient indexes are calculated per 100 g, and use the nutrient contents available from the National Food Composition Database in Finland - Fineli®, maintained by the Nutrition Unit of the National Institute for Health and Welfare (THL, 2017). Both indices can obtain values ≥ 0, and a value of 100 indicates the full nutritional value at DRI, while values > 100 indicate the nutrient contents exceeding DRI. Nutrient indexes are often used so that the amount of each nutrient do not exceed DRI, but I took the whole amount into account, because the content of individual nutrients in 100 g of food is usually clearly below the DRI and hardly more than the safety amount. In practice, values for protein sources seldom exceed DRI. These situations can exist, however, particularly regarding fat-soluble vitamins in vegetable oils. Even then those exceeding the values can be beneficial to health in a dietary context, and thus they benefit the nutritional quality of the product.

NR9 was used as originally presented by Fulgoni et al. (2009). The nine nutrients included are macronutrients, protein and fibre, and micronutrients Ca, Fe, Mg, K, Vit A, C and E. $FNI_{prot}7$ was developed in the present study as an index for products serving as protein sources (Article III). Seven nutrients were included in $FNI_{prot}7$: macronutrients protein, MUFA and Polyunsaturated fatty acids (PUFA), and micronutrients Ca, Fe, riboflavin (B2) and Folic acid (B9).

I used two different nutrient indexes, because I wanted to evaluate how large the difference was between product-group-specific ($FNI_{prot}7$) and general indexes (NR9). General indexes have been applied widely, but to my knowledge this is the first time a product-group-specific index has been applied. The idea in developing $FNI_{prot}7$ was to include nutrients that are especially important to the product group at hand, i.e. protein sources, in the index. The choice of nutrients was based on nutrition expertise on what nutrients are crucial for protein sources in the context of a Finnish diet. The core idea was that these nutrients are relevant from the point of view of public health in Finland, and sufficient intake of these nutrients is currently dependent on typically consumed protein sources. This emphasizes the dietary context and consumer choice, which is usually product-group-specifically directed. However, this index is not necessarily applicable in other dietary contexts.

Nutrient indexes used as FUs may be more difficult to understand than kilos or grams, for example, at least by a lay person. The outcome of the assessment of climate impact, for example, is GWP per unit of nutrient index. A unit of the nutrient index expresses one per cent of the average nutrient content in relation to those nutrients' DRIs in 100 g of a food. Thus, it does not refer to any amount of the food itself. Because of this, alongside these FUs I used a reference flow (RF) for the FUs, i.e. an amount of product fulfilling the FU (ISO 14400:2006; ISO 14040:2006), i.e. a unit of the nutrient index for the product. The RF for an FU thus describes how much of a product at hand is needed to provide a nutrient intake that equals one unit of the nutrient index. The RF is low for nutrient dense foods and high for foods whose nutrient density is low. By using these two measures, the nutrient index as an FU and the RF together, it can be assessed whether a food product is a good and eco-efficient source of crucial nutrients for the product group at hand.

Table 8. Functional units (FUs) based on nutrient indexes used in the study (Article III).

Item	Unit	Source
A general nutrient content of foods	unit of NR9*	Fulgoni et al. (2009)
A general nutrient content of protein source foods	unit of $FNI_{prot}7$*	Article III

*equals to 1 % average nutrient intake from DRI regarding nutrients including in the index

4.5 A METHOD TO IDENTIFYING SUSTAINABLE FOOD PRODUCTS

In this dissertation, a novel method to identify sustainable food products is introduced and demonstrated (Article III). It is based on the use of a nutrient index as an FU and links a consideration of restricted nutrients as a separate measure. These measures are LIM2 or LIM3 (Fulgoni et al., 2009) (Article III). From the point of view of nutritional science, it is essential to take both beneficial and harmful nutrients into account.

In the method introduced in this dissertation (Figure 5), the LCA for products is first performed by using a nutrient index as an FU and then a LIM index is calculated for the amount of a product which fulfils a unit of the nutrient index for the product (Reference flow, RF). I used LIM2 linked to the protein-source-specific nutrient index (FNIprot7) and LIM3 linked to a general nutrient index (NR7) because of their suitable nutrient composition for the studied products groups. Sustainable products can be defined by setting a threshold for both LCA values (which are obtained by using a nutrient index as an FU) and the LIM index scores (which is calculated for a corresponding RF).

Tentative thresholds are introduced in Article III. A tentative threshold value for the GWP/nutrient index set in the dissertation is 0.2 kg CO2-eq per unit of the nutrient index. A unit of the nutrient index means an average percentage point of proportional (beneficial) nutrient intakes. Assuming that 100 % means the theoretical fulfilment of a nutrient requirement, 1 percentage point is not much. Protein sources fulfil a certain portion and other product categories fulfil other portions. These should be taken into account, when the threshold is set. This consideration is, however, beyond the scope of this dissertation, but it requires further research. A tentative threshold value for the LIM for the RF set in the dissertation is 2. The RF means the amount of food fulfilling a unit of the nutrient index. The LIM for the RF means the average percentages of the proportional (harmful) nutrient intake in the amount of food fulfiling a unit of the nutrient index. Thus, value 1 would mean that there are equal proportions of harmful and beneficial nutrients in that food product. Value 2 means that the proportion of harmful nutrients would be double that of beneficial nutrients. Value 1 is thus a kind of boundary. However, nutrient index values are not natural numbers which can self-evidently be used in all kinds of mathematical operations and comparisons. First, the nutrient index value for a food is dependent on the number of nutrients it includes; the more nutrients it contains, the smaller the value of the nutrient index is (Saarinen, 2012). The LIM index consists of far fewer nutrients than found in the positive nutrient indexes. In addition, and even more importantly, the amount of harmful nutrients is unequally distributed between food categories. Assuming that a diet can include a certain number of harmful nutrients (without causing any harm), this may lead to a situation in which harmful nutrients are consumed proportionally more from some foods. This complicated issue should be taken into account when the threshold is set, and thus, the setting of thresholds needs further research and interdisciplinary collaboration. I have set tentative thresholds based on pure speculation without any calculation behind them.

LIM3 consists of Na, SAFA and added sugar, LIM2 includes only Na and SAFA. The formulas are:

(5) LIM3 = $\sum_{i=1-3} \frac{nutrienti}{DAi} \times 100/3$ (Fulgoni et al. 2009)

(6) LIM2 = $\sum_{i=1-2} \frac{nutrienti}{DAi} \times 100/2$ (Fulgoni et al. 2009)

In these formulas, nutrient means the amount of nutrient i in 100g of a food product, and DAi is the daily allowance for the intake of nutrient i.

Basically, these LIM indexes are much like environmental impact category indicators in the LCA representing harmful and unintended consequences from consuming a product. However, the LIM indexes do not contain any characterization in a sense that effects of separate nutrients on nutritional conditions of person would have been standardised based on an impact mechanism and then summed up. Nutrients are still normalised by using DAs, which makes it possible to sum them up.

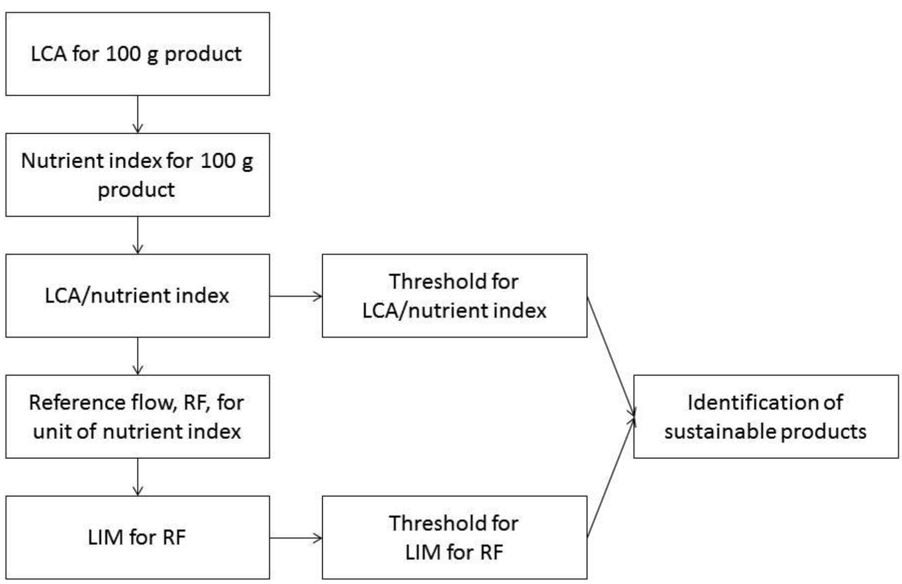

Figure 5. Outline of the method to identify a sustainable food product.

5 RESULTS

5.1 TRADITIONAL LIFE CYCLE ASSESSMENTS FOR PRODUCTS

The GWP values from traditional LCAs without taking nutrition into account (Article I) are presented in Table 9. Animal-based foods, particularly Emmental cheese, have multiple GWP scores compared to plant-based products, but it is obvious that some products are not comparable because of their varied function in a diet or a meal. They are merely complementary rather than alternative products. However, broiler fillet and Emmental cheese are both regarded as protein sources. The GWP for Emmental cheese is higher than for broiler fillet almost by a factor of four. This raises the question of how taking nutrition into account would alter the relationship between these two products.

Table 9. Global warming potentials (GWP) from traditional Life Cycle Assessments (LCA) without taking nutrition into account (Article I). FU means functional unit for LCA.

	kg CO2 eq per FU	FU
Cucumber	0.39	kg
Oat flakes	0.83	kg
Beer	0.54	l
Potato flour	0.66	kg
Broiler fillet, marinated	3.6	kg
Emmental cheese	12.97	kg
Gratinated potato	0.54	kg

5.2 LIFE CYCLE ASSESSMENTS FOR STANDARDISED LUNCHES

GWPs for standardised home-made and ready-to-eat lunches (Article II), as well as the characteristics of the lunches, are presented in Table 10. The results are also divided according to the parts of the portions and phase of the production chain. In Article II, the results for school lunches are also presented but the FU for them (i.e. lunches actually eaten in a school canteen with no nutritional standardization) differ from home-made and ready-to-eat lunches. Thus, results for them are not comparable to the latter ones, and they are not presented here.

The portion size of each part of the lunches varied between the lunches (Table 10) due to the definition of the FU (i.e. the lunch plate model with nutritional standardisation based on the nutrient recommendations, as well as focusing on typical foods and their typical portions as far as possible). A portion size for the majority of the main dishes was between 300-350 g, but it was smaller for a couple of the home-made chicken-based meals (lunches 6 and 7) and larger for some of the plant-based lunches (9, 10, 11, 13, 21). In particular, a portion size (500 g) for porridge-based lunches (13 and 21) was considerably larger than for others due to the low energy density of porridge. For porridge-based lunches, a slice of cheese had to be added to a slice of bread so that the energy requirement would be fulfilled. In contrast, there is no particular need for salad in these lunches because berries were included in the main dish.

The share of the main dish of the total GWP of the lunches varied from 33 to 64 %, and correspondingly the share of salad was 11-23 %, the share of bread was 4-33 %, and the share of drinks were 0-33 %. Thus, each part of the lunch can make a difference within a lunch. In contrast, based on these results, the GWP of a lunch is not clearly dependent on a choice between potatoes, pasta or rice; it is a matter of the overall recipe and the composition of the lunch.

Within the whole range of lunches, the GWP varied between 0.98 and 3.81 kg CO_2 equivalents per lunch. Thus, the lunch with the largest GWP (home-made minced meat casserole) caused an almost 6-fold GWP compared to the lunch with the lowest GWP (home-made vegan broad bean patty and mashed potatoes), while most of the home-made non-vegetarian lunches and ready-to-eat-lunches caused approximately a 2 to 3-fold increase in the climate impact. In turn, the GWP for most of home-made vegan and home-made vegetarian lunches were close to the lowest GWP. The porridge-based lunch (13) was an exception with a relatively high GWP due mainly to the addition of cheese.

Table 10 a) Main results for standardised home-made and ready-to-eat lunches: composition of lunches (Article II)

	Main dish (g)	Salad (g)	Bread (g)	Spread (g)	Drink (dl)
			Home-made lunches		
1	Frankfurters and mashed potatoes (340)	cucumber-tomato-salad, carrots (150)	rye bread (90)	vegetable spread 70% (9)	skimmed milk (2)
2	Ham casserole (350)	cucumber-tomato-salad, carrots (150)	wheat bread (80)	vegetable spread 70% (8)	skimmed milk (2)
3	Chicken casserole (350)	cucumber-tomato-salad, carrots (150)	wheat bread (70)	vegetable spread 70% (7)	skimmed milk (2)
4	Rainbow trout casserole (350)	cucumber-tomato-salad, carrots (150)	rye bread (100)	vegetable spread 70% (10)	skimmed milk (2)
5	Minced meat macaroni casserole (370)	cucumber-tomato-salad, carrots (150)	rye bread (50)	vegetable spread 70% (5)	skimmed milk (2)
6	Chicken sauce and whole-meal pasta (260)	cucumber-tomato-salad, carrots (150)	wheat bread (70)	vegetable spread 70% (7)	skimmed milk (2)
7	Chicken sauce and whole-meal rice (250)	cucumber-tomato-salad, carrots (150)	rye bread (90)	vegetable spread 70% (9)	skimmed milk (2)
8	Vegetable casserole (lactoveg) (350)	cabbage-blackcurrants (150)	wheat bread (80)	vegetable spread 70% (8)	skimmed milk (2)
9	Broad bean patty and mashed potatoes (veg) (410)	cabbage-blackcurrants (150	rye bread (70)	vegetable spread 70% (7)	
10	Soy bean patty and mashed potatoes (veg) (410)	cabbage-blackcurrants (150)	wheat bread (70)	vegetable spread 70% (7)	
11	Soy bean patty and mashed potatoes (lactoveg) (370)	cabbage-blackcurrants (150)	rye bread (70)	vegetable spread 70% (7)	skimmed milk (2)
12	Beetroot patty and barley (lactoveg) (330)	cabbage-blackcurrants (150)	wheat bread (70)	vegetable spread 70% (7)	skimmed milk (2)
13	Barley porridge and berry fool (500)	carrot sticks, cucumber (150)	wheat bread (70)	veg. spread 70%, cheese (32)	skimmed milk (2)
14	Chicken-pasta (350)	cucumber-tomato-salad, carrots (150)	wheat bread (70)	vegetable spread 70% (7)	skimmed milk (2)
			Ready-to-eat lunches		
15	Ham casserole (300)	cabbage-root vegetables, tomatoes (150)	wheat bread (100)		skimmed milk (2)
16	Vegetable casserole (300)	cabbage-root vegetables, tomatoes (150)	wheat bread (100)	vegetable spread 70% (7)	skimmed milk (2)
17	Chicken-pasta (300)	cabbage-root vegetables, tomatoes (150)	wheat bread (75)	vegetable spread 70% (7)	skimmed milk (2)

18	Chicken in cream sauce and rice (350)	cucumber-salad, tomatoes (150)	wheat bread (30)		skimmed milk (2)
19	Minced meat macaroni casserole (320)	cabbage-root vegetables (150)	rye bread (50)	vegetable spread 70% (5)	skimmed milk (2)
20	Rainbow trout casserole (300)	cabbage-root vegetables, tomatoes (150)	wheat bread (90)	vegetable spread 70% (10)	skimmed milk (2)
21	Barley porridge and berry fool (500)	cucumber (50)	rye bread (70)	cheese (25)	skimmed milk (2)

Table 10 b) Main results for standardised home-made and ready-to-eat lunches: Global warming potential (GWP), kg CO_2-eq per standardised lunches and divided by part of the portions and phase of the production chain, and GWPs of portions compared to the lowest GWP among the portions. (Article II)

	Energy content of lunches	GWP	main dish	salad	bread	drink	GWP compared to the lowest GWP
	kcal	kg CO_2	%	%	%	%	times
			Home-made lunches				
1	738.8	1.90	39	31	12	18	2.9
2	729.2	2.20	49	26	9	15	3.4
3	737.4	1.98	42	30	10	18	3.0
4	739.0	2.07	41	29	13	17	3.2
5	731.1	3.81	68	19	4	9	5.9
6	735.2	1.97	45	29	9	17	3.0
7	728.4	2.09	46	27	11	16	3.2
8	739.2	1.34	47	12	16	25	2.1
9	735.0	0.65	47	20	33	0	1.0
10	733.8	0.80	56	17	27	0	1.2
11	737.7	1.17	44	13	15	28	1.8
12	737.1	0.98	35	14	18	33	1.5
13	744.5	1.92	35	16	32	17	3.0
14	746.1	1.85	41	31	10	18	2.8
			Ready-to-eat lunches				
15	728.0	1.75	48	22	11	19	1.1
16	741.5	1.77	47	21	13	19	1.1
17	736.2	1.86	51	20	11	18	1.1
18	732.8	2.35	49	32	4	14	1.4
19	730.0	1.91	64	11	8	17	1.2
20	732.0	1.63	46	23	10	21	1.0
21	730.9	1.80	33	17	32	18	1.1

5.3 LIFE CYCLE ASSESSMENTS FOR FOOD PRODUCTS WITH LINKING NUTRITION IN THE ASSESSMENT

5.3.1 CORRELATION TEST

The results from the correlation test are shown in Table 11 (Article III). Some positive linear associations between the GWP and protein as well as negative linear associations between the GWP and folate and zinc can be seen in the results. However, as a whole, the correlation test does not support correlations between any of those factors due to their low p-values.

Table 11. Pearson's product-moment correlations between GWP of products (g CO_2 eq per 100 g) and selected individual nutrients in products (an amount in 100 g) (Article III). Source of the Table Saarinen et al. 2017.

	cor with GWP	df	p-value	95% confidence interval
Protein	0.57	27	0.001	0.27 – 0.78
Polyunsaturated fatty acids, PUFA	-0.19	27	0.326	-0.52 - 0.19
Monounsaturated fatty acids, MUFA	-0.05	27	0.779	-0.41 - 0.32
Calcium (Ca)	0.10	27	0.588	-0.27 - 0.45
Iron (Fe)	0.10	27	0.588	-0.27 - 0.45
Folate	-0.38	27	0.041	-0.66 - -0.02
Vitamin B2	0.25	27	0.199	-0.13 - 0.56
Vitamin B12	0.08	27	0.694	-0.30 - 0.43
Selenium (Se)	0.22	27	0.246	-0.16 - 0.54
Zinc (Zn)	0.38	27	0.041	0.02 - 0.66
Saturated fatty acids, SAFA	0.29	27	0.124	-0.08 - 0.60
Sodium (Na)	0.09	27	0.645	-0.29 - 0.44

5.3.2 GWPS PER QUANTITY OF PRODUCTS, NUTRIENT INDEXES FOR PRODUCTS, REFERENCE FLOWS FOR NUTRIENT INDEXES AND REFERENCE AMOUNTS FOR DAILY RECOMMENDED INTAKES

A summary of the main quantitative results from the test calculations (Article III) for 18 selected foods (from a total of 29 analysed in the dissertation) is shown in Table 12. The results consist of the GWP scores per quantity of individual nutrients and per $FNI_{prot}7$, RF for $FNI_{prot}7$ and RA for DRI. The results for all 29 products are presented in Article III, in Tables 3, 4 and 6.

Two of the products, and related LCA-models, in Table 12 are from Article I, namely broiler fillet in marinade and Emmental cheese. However, the marinade was subtracted from the broiler fillet model and then the preparation phase was added to the model (the GWP for the broiler in marinade was 3.6 kg CO_2-eq per kg of (uncooked) product, but 5.2 kg CO_2-eq per kg of broiler without marinade, and 6.86 kg CO_2-eq per kg of fried broiler slices). The rest of the products are from Article III.

The GWP value based on 100 g of a product was highest for other animal-based foods than Finnish wild fish, and was the lowest for plant-based foods and Finnish wild fish. In general, the ranking was the same also for the GWP based on the $FNI_{prot}7$ nutrient index, but there were changes in rankings within a group of meat, cheese and eggs, and within a group of nuts, beans and seeds. In particular, hemp seeds, Hazelnuts, beef and soybeans were doing relatively better when $FNI_{prot}7$ nutrient index was used as an FU, in contrast to cheese, broiler and beans. Additionally, the LIM2 values were lowest for plant-based-foods, in general. The ranking of foods based on the GWP values when the FUs were a mass-unit for individual nutrients varied, but in general, Finnish wild fish performed well compared to others with only a few exceptions. For some nutrients, however, the RAs for the DRI of Finnish wild fish were among the highest values, as well as for plant-based foods. The RF for a unit of $FNI_{prot}7$ varied greatly within the whole set of the foods. The LIM2 value for $RF(FNI_{prot}7)$ was, in general, the lowest for plant-based foods but also varied a lot.

Table 12. The main results for 18 selected foods: the Global warming potential (GWP), kg CO_2-eq per FU; reference amounts (RA) for the daily recommended intake (DRI) of nutrients; reference flows (RF) for a unit of the $FNI_{prot}7$ index.

	kg CO_2-eq per (RA for DRI, g)(RF, g ($FNI_{prot}7$))												
	100 g	$FNI_{prot}7$	protein g	Pufa g	Mufa cis g	Fe mg	Ca mg	Folate µg	B2 mg	Se µg	Zn mg	B12 µg	LIM2 per RF(FNI_{prot}
Meat, cheese and eggs													
Beef, fried	1.921	0.137 (7.1)	0.066 (290)	1.067 (1040)	0.504 (980)	0.457 (360)	0.160 (7880)	1.921 (360)	9.605 (680)	0.090 (240)	0.377 (200)	1.921 (150)	1.11
Mutton, cooked	1.921	0.169 (11.8)	0.077 (340)	3.202 (3130)	0.424 (830)	0.768 (600)	0.107 (5250)	0.320 (7090)	9.605 (680)	0.108 (290)	0.640 (350)	1.921 (180)	2.04
Broiler slices, fried	0.686	0.061 (8.8)	0.026 (340)	0.327 (890)	0.139 (760)	0.858 (1880)	0.040 (5560)	0.049 (3040)	3.530 (680)	0.045 (340)	0.490 (740)	0.686 (180)	0.40
Cheese, Emmental	1.297	0.266 (4.0)	0.046 (380)	1.853 (2680)	0.184 (530)	6.485 (7540)	0.002 (110)	0.065 (2130)	4.323 (450)	0.067 (270)	0.371 (300)	0.649 (90)	1.84
Cheese, Edam	0.750	0.163 (3.9)	0.028 (310)	1.250 (3130)	0.126 (630)	3.750 (7540)	0.001 (110)	0.038 (2130)	1.875 (450)	0.037 (250)	0.179 (250)	0.375 (90)	1.55
Eggs, boiled	0.198	0.014 (7.2)	0.015 (650)	0.165 (1560)	0.059 (1120)	0.079 (600)	0.003 (1660)	0.003 (730)	0.496 (340)	0.008 (210)	0.142 (740)	0.099 (90)	0.46
Fish													
Rainbow trout, roasted	0.572	0.048 (6.9)	0.030 (440)	0.110 (360)	0.070 (460)	1.144 (3020)	0.004 (630)	0.064 (4730)	5.720 (1350)	0.037 (340)	1.144 (2070)	0.144 (40)	0.99
Tuna, tinned	0.335	0.037 (10.8)	0.015 (380)	0.209 (1170)	0.472 (5280)	0.116 (520)	0.030 (8590)	0.112 (1418)	3.350 (1350)	0.008 (120)	0.239 (740)	0.067 (40)	0.98
Spiced/ salted herring	0.128	0.011 (8.4)	0.011 (700)	0.051 (750)	0.026 (750)	0.075 (890)	0.002 (1200)	0.064 (2126)	0.427 (450)	0.006 (240)	0.128 (1040)	0.018 (30)	5.30
Baltic herring, fried	0.013	0.001 (6.6)	0.001 (530)	0.004 (650)	0.003 (970)	0.011 (1260)	0.000 (280)	0.001 (3270)	0.065 (680)	0.001 (290)	0.005 (430)	0.001 (20)	0.20
Perch, fried with butter	0.013	0.002 (13.9)	0.001 (500)	0.022 (3130)	0.008 (2220)	0.043 (5030)	0.000 (830)	0.003 (10630)	0.130 (1350)	0.000 (180)	0.016 (1290)	0.007 (90)	2.58
Vendace, fried	0.013	0.001 (7.3)	0.001 (420)	0.004 (630)	0.004 (1210)	0.012 (1370)	0.000 (470)	0.001 (3040)	0.130 (1350)	0.001 (230)	0.003 (250)	0.007 (90)	0.79
Nuts, beans and seeds													
Hemp seeds	0.163	0.003 (2.2)	0.007 (340)	0.005 (60)	0.051 (1180)	0.012 (110)	0.001 (650)	-	1.628 (1350)	-	0.023 (150)	-	0.12
Hazelnuts	0.161	0.004 (3.6)	0.011 (600)	0.037 (430)	0.005 (110)	0.045 (420)	0.001 (680)	0.002 (590)	1.606 (1350)	0.080 (2590)	0.080 (520)	-	0.24
Peanuts	0.130	0.004 (3.5)	0.005 (320)	0.011 (160)	0.008 (220)	0.045 (520)	0.002 (1210)	0.001 (390)	1.298 (1350)	0.043 (1730)	0.042 (330)	-	0.44
Broad beans, cooked	0.067	0.008 (12.5)	0.008 (1030)	0.337 (9380)	0.841 (46880)	0.045 (1010)	0.002 (2630)	0.001 (410)	0.673 (1350)	0.026 (1990)	0.067 (1040)	-	0.61
Soybeans, cooked	0.062	0.004 (6.3)	0.004 (530)	0.015 (460)	0.122 (7350)	0.016 (400)	0.001 (1260)	0.001 (360)	0.624 (1350)	0.007 (600)	0.125 (2070)	-	0.16
Peas, cooked	0.020	0.003 (12.8)	0.003 (1410)	0.040 (3750)	0.200 (37500)	0.009 (660)	0.002 (2700)	0.000 (900)	0.100 (680)	0.029 (13890)	0.013 (690)	-	0.05

5.3.3 A METHOD FOR DISTINGUISHING BETWEEN SUSTAINABLE AND UNSUSTAINABLE FOOD PRODUCTS

The method for distinguishing between sustainable food products is illustrated as a coordinate system with two dimensions: with the GWP/nutrient index on the x-axis and the LIM/RF on the y-axis (Figures 6 and 7). Whether the product can be defined as sustainable or unsustainable is dependent on the limit values set for both the GWP/unit of nutrient index and the LIM/RF, and in reference to which nutrient index has been applied. According to the tentative limit values set in Article III, other products than spiced/salted herring, grilled sausage (meaty), mutton (low-fat, cooked), Emmental cheese, and pike, perch and whitefish (fried with butter) could be classified as sustainable products when GWP/FNI$_{prot}$7 and LIM/RF(FNI$_{prot}$7) were applied. GWP/NR9 and LIM/RF(NR9) resulted in partly the same, but fewer products being classified as unsustainable, namely spiced/salted herring, grilled sausage (meaty), mutton (low-fat, cooked) and Emmental cheese, and also Edam cheese. It is notable that the large difference between Emmental and Edam cheese in the GWP/nutrient index is mostly due to the different allocation ratio between cheese and whey, not due to real differences in production chain practices other than more effective utilization of whey in production of Edam. Notably, beef was classified as a sustainable product according to both measures.

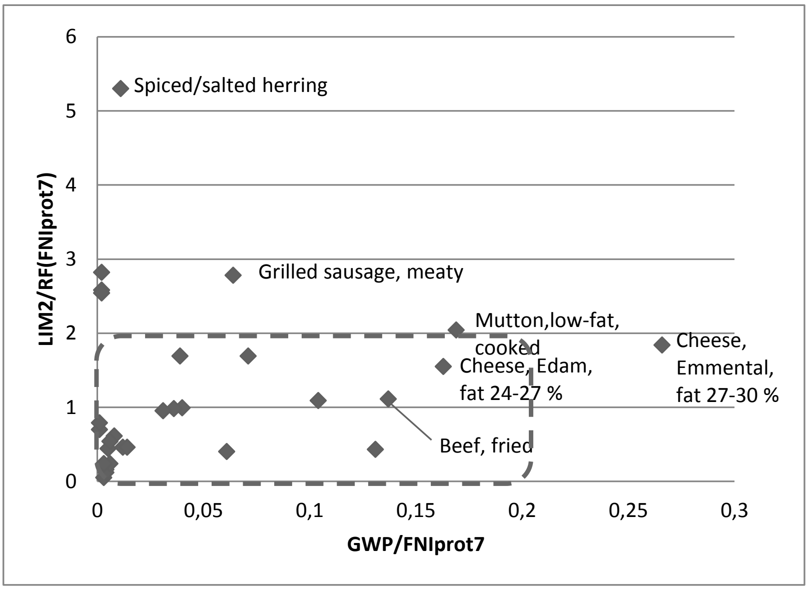

Figure 6. Illustration of a method for distinguishing between sustainable and unsustainable food products using FNI$_{prot}$7 as FU in LCA (Article III). Source of the Figure Saarinen et al. 2017.

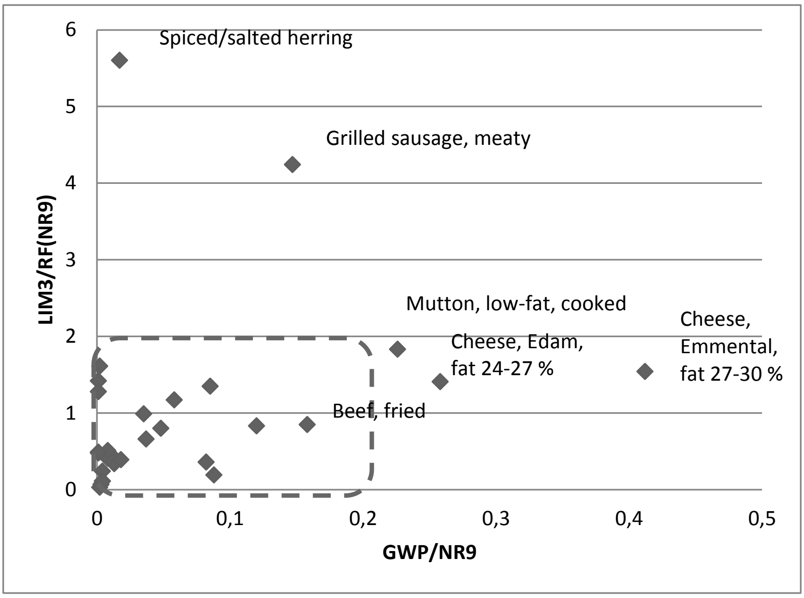

Figure 7. Illustration of a method for distinguishing between sustainable and unsustainable food products using NR9 as FU in LCA (Article II). Source of the Figure Saarinen et al. 2017.

5.4 EVALUATION OF THE APPROACHES

The product and meal scale approaches to taking nutrition into account in a food LCA as well as their applicability, advantages and weaknesses as FUs are summarised in Tables 13 and 14. The tables answer a set of research questions 1) How can nutrition be taken into account by FUs in product and meal level LCAs? What kinds of questions can these approaches answer? What kind of information can the approaches provide? The questions are further discussed in sections 5.4.1 and 5.4.2.

Table 13. A summary of different nutritional FUs and their applicability.

FU	Character	Purpose	Advantage	Weakness
NR9	a general nutritional FU	a comparison between a range of foods in general; may be particularly applicable to meals	takes several nutrients into account reflecting the general nutritional quality of food; applicable to all kinds of foods	is not product-group-specific and thus imprecise to some extent; can be misleading, for example, if a food is an essential source of a scarce but essential nutrient
FNI_{prot}7	a product-group-specific nutritional FU	a comparison between a range of protein sources in general	takes several nutrients relevant to protein sources into account; applicable to all protein sources	can be misleading, for example, if a food is an essential source of a scarce but essential nutrient
g protein	a nutrient-specific measure	a comparison between protein sources in protein deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients and the fact that protein is a group of amino acids
g Pufa	a nutrient-specific measure	a comparison between products in Pufa deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients and the fact that PUFA is a group of fatty acids
g Mufa cis	a nutrient-specific measure	a comparison between products in Mufa deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients and the fact that MUFA is a group of fatty acids
mg Ca	a nutrient-specific measure	a comparison between products in Ca deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients
mg Fe	a nutrient-specific measure	a comparison between products in Fe deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients
µg Folate	a nutrient-specific measure	a comparison between products in Fe deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients
mg B2	a nutrient-specific measure	a comparison between products	allows a focused comparison in a	ignores other nutrients

		in B2 deficiency situations	specific situation; can be used particularly in planning the minimum required amount of animal based products within diets rich in plant-based products	
µg Se	a nutrient-specific measure	a comparison between products in Se deficiency situations	allows a focused comparison in a specific situation	ignores other nutrients
mg Zn	a nutrient-specific measure	a comparison between products in Zn deficiency situations	allows a focused comparison in a specific situation; can be particularly used in planning the minimum required amount of animal based products within diets rich in plant-based products	ignores other nutrients
µg B12	a nutrient-specific measure	a comparison between products in B12 deficiency situations	allows a focused comparison in a specific situation; can be used in planning the minimum required amount of animal based products within diets rich in plant-based products	ignores other nutrients
standardised lunch	a general measure for comparative meals	a comparison between nutritionally corresponding meals	promising model to be used in practical sustainability education, for example in canteens	is not quite univocal; can be misleading if the real portion a consumer takes is incompatible with the model plate

Table 14. A summary of measures for nutrients to be limited and their applicability.

Measure	Character	Purpose	Advantage	Weakness
LIM3	a general measure for nutrients to be limited; including three nutrients	a comparison between a range of foods in general; to be used together with a general nutrient index based on recommended nutrients, for example NR9, for defining sustainable foods	takes several nutrients into account reflecting the general nutritional quality of food; applicable to all kinds of foods	is not product-group-specific and thus imprecise to some extent; can be misleading, for example, if a food is an essential source of a scarce but essential nutrient
LIM2	a general measure for nutrients to be limited; including two nutrients particularly important for protein sources	a comparison between a range of protein sources in general; to be used together with a general nutrient index based on recommended nutrients, for example $FIN_{prot}7$, for defining sustainable foods	takes several nutrients relevant to protein sources into account; applicable to all protein sources	can be misleading, for example, if a food is an essential source of a scarce but essential nutrient

6 DISCUSSION

The hypothesis of this dissertation was that nutrition could be taken into account in a food LCA on the product and the portion scales so that relevant additional information could be achieved compared to the current LCA practice. The focus of the work was at a product and portion level because a primary consumer choice operates in that context. At product level, a product-group-specific approach was emphasized, and protein source foods were highlighted as an example of a product group. These starting points proved to be successful: the methods developed and tested in the dissertation were justifiable and they provided new insights and results. Focusing on a product-group-specific approach for protein sources provided a valuable pathway to establishing advanced nutritional FU to be used in food LCAs and this has already been applied by other authors (McAuliffe et al., 2018).

6.1 HOW CAN NUTRITION BE INTEGRATED TO FOOD LCA?

According to the correlation test, the GWP of a product is not dependent on any measure of nutritional quality (Table 11). This holds true even for protein due to the low p-value, although a correlation between protein content and GWP were reasonably high, and thus the test did not support a linear association between the factors. I did not find a correlation between different nutrients either (data not shown). The test showed that there is a need for an integrated method to consider environmental impacts and nutritional quality in parallel, if it is wanted to take both aspects into account. Thus, it would be over simplified to suppose that more nutritious foods were more of a burden on the climate. It would likewise be an over-simplification to say that less nutritious foods are less of a burden.

According to the results, the inclusion of nutritional data in food LCAs on the portion scale can be done by using a standardised lunch as an FU. The standardisation could be based on the lunch plate model and extended by quantitative definitions, such as a recommended distribution of energy from proteins, carbohydrates and fatty acids (Table 3). Only quantitative definitions enable a sensible comparison on a nutrition basis, because there is significant potential variation of the nutrient content between foods within parts of the plate model (i.e. main dishes, side dishes, salads, breads and drinks). In the lunch plate model, the amount of food is illustrated in the visual parts of the plate and thus the real nutrient content of lunches can vary.

A standardised lunch could be used as a general measure in comparisons between meals (Table 13). It is a promising method for use in sustainability education for consumers, particularly in practical situations, such as providing information to customers in canteens, because it is familiar to most consumers. However, even the information provided based on a standardised lunch is not quite univocal. It could be misleading if the real portion that a consumer actually takes from the food line is incompatible with the model plate and nutritional standardisation. In practical situations this should be taken into account as the informational material is designed.

An approach to using a standardised lunch (based on the lunch plate model and further nutritional recommendations) as an FU can be utilised also in the ecodesing of meals or scanning for alternatives for an ingredient in the meal or for a life cycle phase of the production-consumption chain which has a high environmental impact. In such a manner, at first an LCA for a certain meal could be done and hotspots could be identified. Then alternatives could be tested. For alternative ingredients, it is important to adjust the whole meal to still fulfil the definition of the FU, including the nutritional requirements. Results for home-made and ready-to-eat minced meat casserole in this dissertation illustrate this kind of situation (although the replacement of ingredients in ready-to-eat meals was supposedly not made based on environmental impacts but merely cost): the meat in home-made food was minced beef, but in the ready-to-eat food the meat was broiler. This difference largely explains the difference in the climate impact of those meals (Table 10a). Reducing the amount of a component which has a high environmental impact is another option for ecodesing a meal. In these cases however, the net reduction of the impact of the meal is always lower than the decrease in the impact linked to the reduced component, because an amount of other components has to be increased so that the definition of the FU is still fulfilled. It is notable that all of modifications to meals (which are carefully constructed according to the definition of the FU) always mean moving away from current consumer practices. It is also notable that, the FU for the meals used in this dissertation already includes requirements that are not widely met in current meals. Thus, these modifications can be seen merely as future anticipation rather than a pure comparison of current meals.

To my knowledge, Article II was the first and still is the only study utilizing the plate model with further specifications for nutritional features based on nutritional recommendations interpreted as an FU in a food LCA. The results from the study are also presented in Virtanen et al. (2011) in relation to the results of a food LCA based in the IO-LCA approach. Davis and Sonesson (2008) and Davis et al. (2010) used nutritional recommendations as a basis for the specification of the nutritional quality of meals (using a meal as an FU) in the same way as we did in Article II, but they did not use the actual plate model as a basis for meal construction. Contrary to our method, other published LCA studies on meals do not include nutrition explicitly in the description of a target product or the FU (see Calderón et al., 2010; Hanssen et al. 2017; Rivera et al. 2014; Rivera and Azapagic, 2015; Sanfilippo et al., 2012; Sonesson et al., 2005). In other cases, nutritional aspects have been much more narrowly considered as in Carlsson-Kanyama (1998), who used standardised energy and protein contents as a basis for meal construction, or in Jungbluth et al. (2016) who used the protein content in their conference article.

According to the results of this study, mass-based FUs for individual nutrients can be used in comparisons between products in a specific situation, such as when there is a deficiency of a certain nutrient (Tables 12 and 13). A reference amount (RA) for each nutrient, i.e. an amount of product fulfilling the DRI of the nutrient, should however be used alongside these FUs, because the RA reveals whether the food product in question is a reasonable source of the nutrient in the first place. By using these two measures together it can be assessed if whether a food product is a good and eco-efficient source of the required nutrient.

A shortcoming of mass-based FUs for individual nutrients is that they ignore other nutrients, and for proteins and fatty acids, they ignore that these nutrients are actually a group of substances (Table 13). The composition of these substances affects the quality of the proteins and fatty acids. These nutrients should be treated by an approach similar to nutrient indexes, as Tessari et al. (2016) and Sonesson et al. (2017) did for proteins.

Tessari et al. (2016) used three FUs: 100 g of a product, 13 g of the total EAAs (corresponding to the DRI of EAAs) and the amount of food corresponding to the DRI of limiting EAAs. According to their results, large advantages in the production of crop foods compared to animal foods still remain, but these decrease remarkably when human requirements for EAAs are used for reference. They also showed that soybeans are the best source of overall EAAs considered on a mass-basis (100 g of an edible part of a product), followed by chicken and beef. This approach is interesting, and it provides new knowledge into the eco-efficiency of protein sources. The EAA content is an essential feature of protein sources. The value of the work by Tessari et al. (2016) however is slightly reduced by their use of dry matter content as a basis for the calculation of the EAA for plant-based products, but the fresh weight for meats. Thus, the results are not fully comparable. It also needs further research to evaluate the (recalculated) results in relation to the eco-efficiency of foods as a source of other essential nutrients, and in relation to nutrient indexes, particularly the product-group-specific nutrient index. In addition to individual foods, Tessari et al. (2016) assessed three combinations of foods, typically a combination of grains and legumes. This kind of combination moves towards the plate model, and their results support the findings in Article II (section 4.2.).

The approach by Sonesson et al. (2017) corrects the mass-based FUs of the products under study by a specific correction factor. They use the protein quality index PQI, for the product (for example 1 kg food is equal to (1 * PQI) kg of PQI-weighted food). They provide a step-wise process to produce the PQI for the product, in which the EAA content of a product is proportionate to the EAAs in the diet in a certain time period. Thus, the PQI illustrates the importance of the studied product as an EAA provider in the specific dietary context. According to this, if a product contains EAAs that are lacking in the diet, the PQI of the product will be higher, and vice versa. It is notable, that this approach takes into account several amino acids, which together describe the protein quality of a product, and furthermore, the method achieves this in the context of the diet. It is thus not a real (or simple) individual-nutrient-based approach. The real individual nutrient approach (as used in this dissertation) could also be applied to EAAs. In this dissertation, however, it was not applied, and so a comparison with Sonesson et al. (2017) is not truly possible and would need further research.

According to the results, FUs based on a nutrient index consisting of beneficial nutrients (such as NR9 and $FNI_{prot}7$) is currently the most suitable methodology for including nutrition in a food LCA on a product scale (Tables 12 and 13). Thus, I suggest using them as a baseline method for including nutrition in a food LCA on a product scale. Foods are typically sources of several nutrients, so by using nutrient indexes it is possible to include several nutrients in the FUs and thus provide a wider (or general) view of the nutritional quality of a product into a food LCA in one figure. It also enables a comparison between products based on nutritional quality. The approach is compatible with the idea of an FU as a description of the benefits of a product (i.e. the reason for consuming it). This is because a nutrient index based on recommended nutrients includes only beneficial nutrients. There are naturally also other reasons to consume food products than nutrition alone, but these are beyond the scope of this dissertation.

Both of the types of indexes comprehensively analysed in this dissertation, namely a general nutrient index (NR9) and a product-group-specific nutrient index ($FNI_{prot}7$), can be applied as FUs (Table 13). Their results however vary, which is discussed further in section 5.5. I suggest $FNI_{prot}7$ to be used as an FU in LCAs of protein sources. It is a product-group-specific index and is designed to be compatible for comparing products within a product group because it consists of nutrients which are especially important to this product group in the context of diet. NR9 can be used to differentiate products across all product categories. This is because it reflects the general nutritional quality of products in the context of diet. NR9 is more suitable for ready-to-eat products which consist of protein sources and other types of ingredients.

I chose to use a nutrient index based solely on beneficial nutrients, although from the point of view of nutrition science, nutrient indexes based on both recommended and restricted nutrients (e.g. NRF9-3 and FNIprot7-2) reflect the nutritional quality of a food product better than nutrient indexes based solely on recommended nutrients (Drewnowski and Fulgoni, 2014). However, validation of nutrient indexes is ultimately based more on the statistical association between the nutrient indexes and a healthy diet (Fulgoni et al., 2009), or expert opinion, than a causal relationship between the integrated effect of positive and negative nutrients on health (or even the nutritional impact). The manner in which positive and negative nutrients are related to each other in formulas for nutrient indexes (i.e. by subtraction, see section 3.4.4) is arbitrary and is not based on strict or precise science. In a commonly used formula for indexes, subtracting the mean of portions of negative nutrients from the daily allowance (DA) of those nutrients from the mean of portions of the positive nutrients from daily recommended intake (DRI) in 100 g of a product (section 3.4.4) gives an arbitrary number without any real meaning. It does not describe the real nutritional quality or impact, but is just an index score. It apparently reflects the nutritional quality of a food, but it is not the only way to do so. Naturally, this does not mean that beneficial and restricted nutrients should not be incorporated in the identification of sustainable products, as was done in the method I introduced.

The method introduced in this dissertation is based on a totally different approach than the suggestion for a nutritional FU by Schau and Fet (2008), which was for a quality corrected functional unit (QCFU). The QCFU follows the principles of energy corrected milk (ECM) and the authors suggest that the contents of fats, carbohydrates and proteins should be corrected by factors which should be set by nutrition specialists. After almost ten years, these factors are still lacking. As is discussed in Article III, ECM is not compatible from the point of view of consumption because some of the fatty acids in milk are harmful to health rather than beneficial (according to the current nutrition recommendations at least). So, if the QCFU is to be developed further, there should be special attention paid to the compatibility of the approach with the consumers' point of view. Furthermore, why not use an established approach to describe the nutritional quality of food, such as the nutrient indexes, rather than creating a new method?

6.2 WHAT KIND OF QUESTION CAN THESE APPROACHES ANSWER?

An LCA that includes a standardised lunch as an FU can provide information on which one of a number of nutritionally corresponding lunches is the most, or the least, eco-efficient regarding impact categories which are chosen to be assessed (Tables 10 and 13). The use of the standardised lunch as FU provides relevant additional information related to the LCA of individual products, such as meat or vegetables, because it takes nutritional quality of typical food combination into account instead of individual products. Individual products are typically not able to provide an adequate nutrient composition intake alone. This method can determine how large an environmental impact will be associated with a specific combination of foods, particularly when the combination meets nutritional requirements (Tables 10 and 13).

Mass-based FUs for individual nutrients can answer the question of which one of a range of food products is the most eco-efficient source of a certain nutrient regarding impact categories which are chosen for assessment (Tables 10 and 13). This is a particularly valuable feature regarding essential but scarce nutrients. This is further discussed in section 6.3.2.

It is, however, notable that FUs based on the quantity of protein, as is presented in this dissertation, does not take amino acids into account, contrary to Tessari et al. (2016) and Sonesson et al. (2017). Proteins consists of amino acids, and some of them are essential, but scarce in plant-based foods, so that to ensure the intake of all of them, two or several foods have to be consumed at the same time or, at least, on the same day for adults. Instead, meat contains all of them. This affects comparisons between meat and plant-based protein sources, but the method I present is not able to display this difference in the nutritional quality of protein sources. The relevance of this shortcoming should be evaluated against the entire diet, because several individual products within a diet may complete the intake of amino acids so that there may not be a need to obtain all the amino acids from one product. Even other type of products than typical protein sources supply significant amounts of proteins, i.e. amino acids such as cereals which are typically considered as sources of carbohydrates (de Boer et al., 2006).

In general, nutrient indexes enable a comparison between products based on the nutritional quality. An LCA applying NR9, which is a general nutrient index, as an FU can determine which one of the products is the most eco-efficient, in general, in the chosen dietary context and regarding the impact categories which are chosen for assessment (Table 13). This kind of general nutrient index takes several nutrients into account reflecting the general nutritional quality of products, and thus I assume it is particularly applicable to meals and convenience products (ready-to-eat meals), which consist of protein sources and other types of ingredients. This should, however, be further evaluated in future studies.

An LCA applying $FNI_{prot}7$, which is a product-group-specific nutrient index, as an FU instead, can determine which one of the protein sources is the most environmentally efficient source of a nutrient typical to protein sources in the chosen dietary context and regarding the impact categories which are chosen for assessment (Table 13). This kind of general nutrient index takes several nutrients into account reflecting the nutritional quality specific to protein sources.

I suggest $FNI_{prot}7$ to be used as an FU in the LCA of protein sources. It is a product-group-specific index and it is designed to be compatible in the comparison of products within a product group because it consists of nutrients which are especially important to this product group in the context of diet. NR9 can be used to differentiate products across all product categories as it reflects the general nutritional quality of products in the context of diet.

It is notable however, that the both of these indexes can be misleading in some situations. This kind of situation can occur particularly if a product is an essential source of a scarce but essential nutrient. If the index does not include this kind of essential nutrient, the assessment will fail to highlight the nutritional significance of the product. To my knowledge these kinds of situations, however, do not relate to typical protein sources in Western diets. For example, vitamin B12 could be this kind of nutrient, if it were not included in the nutrient index.

I tentatively suggest product-group-specific indexes, such as $FNI_{prot}7$ for protein sources, could be used particularly in consumer education or even on product labels, because they take consumer choice better into account than the general indexes. However, there should additionally be some consideration of the nutrients to be limited (see section 6.3.3). Before the final suggestion, the product-group-indexes should however be validated in further research.

Finally, it is notable that in the future, new scientific knowledge on the importance of the food matrix (Fogelholm, 2016; Thorning et al., 2017), microbes in foods (Derrien and van Hylckama Vlieg, 2015) and the role of overall diet in shaping the gut microbiome (Portune et al., 2017; Sighn et al., 2017) may challenge the entire approach of the nutrient indexes. The composition of indexes to be used as FUs will be challenged also by dietary change that may be occurring right now, in which demand for plant-based products has risen, and by an awakening trend to enrich other products than traditional protein sources with plant-based proteins, such as pasta. During this development, the borders between product groups may change in a nutritional sense, but it is unclear whether consumer behaviour will also change, and how quickly. It is also unclear whether the consumption of proteins will rise while the intake of some other nutrients declines. The index approach is suitable for considering these kinds of changes on a product scale, but it is always linked to a certain dietary context (by the nutrient composition chosen to be included in the index). We do not know how our diet will change in the future with the above mention trends, and how the change will affect the average nutrient intake on a dietary scale. Thus, nutrient indexes to be used as FUs should be critically evaluated and adjusted if needed before application in the future so that they will be based on average future diets.

6.3 WHAT KIND OF INFORMATION CAN THE APPROACHES PROVIDE?

6.3.1 RISING AWARENESS OF ENVIRONMENTAL IMPACTS OF FOOD USING STANDARDISED LUNCH

A standardised lunch as an FU is particularly usable in generic food and environmental education and counselling because it is well-known and the visual element makes it easy to understand. The model relates well to everyday life because food is regularly eaten in combined portions, for example lunch portions, and it thus has the potential to be effective (based on an interpretation linked to theories of practice (Warde, 2005)).

I assume however, that relying on purely visual indicators may lead to deceptive information and guidance if the visual plate model is not adjusted to a specific meal so that it would take the variation of a portion size of the different parts of the lunches in relation to different dishes into account. This is important, because the LCA is based on the specific portion sizes of different parts of the lunch, and LCA results are often very sensitive to portion sizes. For example, if nutrition recommendations are followed, a suitable portion of sausages would be smaller than one of lean meat, because sausages typically contain more fat and energy than lean meat. Thus, a portion of sausage should be smaller in a visual lunch-plate-based communication than a portion of lean meat, but furthermore, other parts of the lunch should be adjusted accordingly so that the whole lunch fulfills nutrient recommendation. Similarly, in visual communication a porridge-based meal should be complemented with a slice of bread and a slice of cheese, for example, to be able to offer sufficiently energy for adolescents (see more detail in Article II). Amount of these components clearly affect the LCA results for the entire meal. The result for the environmental impact should thus be informed for the entire lunch, which is visualised with an adjusted lunch plate model. With such an information tool, both nutritional and environmental aspects could be properly and truthfully included in the educational message. Portion sizes of the components of a lunch should primarily be based on nutrient recommendations, and the environmental information should be targeted at those portions together, because together they form a nutritional entity, i.e. the lunch.

A meal scale approach has an advantage compared to individual foods particularly related to consumer education and counselling, because it takes better into account the whole meal, as well as the typical portion sizes and functions of different foods. In addition, consumers are familiar with the plate model. The meal approach in the LCA literature is highly diverse with varied FUs included in the studies. In this dissertation, the definition of an FU was comprehensive compared to other studies on a meal scale. It was based on the plate model with further nutritional requirements. Application of the plate model means that FUs include all parts of the meal, i.e. the main dish, salad or vegetable additions, bread and drinks. This approach leads to a broad conclusion that plant-based meals have lower environmental impacts (in the categories assessed) than animal-based meals. This is in accordance with other meal scale studies in the literature (Calderon et al. 2010; Carsson-Canyama, 1998; Davis et al, 2010; Sanfilippa et al., 2012). In the literature, the extent of this difference varies, and our comprehensive approach confers a smaller difference, in general. Thus, parallel results for environmental impacts can be obtained by different FU definitions for meals, but our approach includes nutritional aspect more precisely in the assessment and this seems to affect the environmental results. Furthermore, our results on the ranking between home-made meals and ready-to-eat meals is in accordance with results by Sonesson et al. (2005) who found higher climate impacts for home-made meals than for ready-to-eat meals, and were in contrast to results by Rivera et al. (2015) and Hanssen et al. (2017). In this respect, further research is needed to get a clearer picture of the issue. This is also related to our finding that the advance of ready-to-eat meals compared to home-made meals is due to the choice of ingredients more than efficiency in the other phases in the production-consumption chain, which is somewhat supported by Davis et al. (2010) who paid attention to energy-efficiency in the manufacture of vegetable-based ingredients. These two latter aspects relate, however, to the improvement potential in the production chain rather than raising sustainability awareness among consumers.

The plate model contains a strong educational message in relation to both the nutrition and the environmental point of view; in both respects, a change on habits is needed. However, the use of a nutrient index at the portion level, as Kägi et al. (2012) did by using two nutrient indexes in an LCA for meals in their conference article, also provides an interesting approach for further research. The plate model approach should be evaluated against this method, and vice versa. The power of using the indexes as FUs is that the outcome is independent of the portion size; in the case of meals this means independency for the portion size of a meal entity, not the portion size of different components in a meal. So, it is notable that nutrient index for a meal will alter if the portion size of the parts of the meal change.

6.3.2 OPTIMIZING INTAKE OF SCARCE NUTRIENTS WITH THE LOWEST ENVIRONMENTAL IMPACTS

According to the results, mass-based FUs for individual nutrients should be applied restrictedly in the cases of scare but essential nutrients which exist only in a few food products (Table 13). It is important to include these foods in the diet (or to take additional nutrient supplements). Vitamin B12 is this kind of nutrient, for example. By using a mass-based FU for the intake of B12, the most eco-efficient sources of vitamin B12 can be identified. According to the results from test calculations, it is Baltic herring followed by wild fresh water fishes (Table 12).

However, the nutrient content and environmental impact (per 100 g) vary independently between foods (Table 12), and thus an even more realistic picture of sustainability of nutrient sources can be reached by using the nutrition recommendation for the nutrient as a reference amount (RA) to determine the amount of food needed for fulfilling the recommended intake (Table 12). If this amount is reasonable, the food product in question is a good source of the nutrient, and if the environmental impact per a mass unit of nutrient is also low the product can be regarded as a sustainable source of this nutrient. For example, according to test results Baltic herring and wild freshwater fish are good sources of vitamin B12, in addition to having low GWP (CO_2-eq per μg) (Table 12). Thus they can be regarded as the most sustainable sources for vitamin B12.

I suggest that this approach should not be used as a baseline method for a food LCA because the LCA results for different products based on mass-based FUs for different nutrients may be fully contradictory. According to the test results (Table 12), the relative climate-efficiency (i.e. CO_2-eq/FU) of a certain food compared to other foods varies depending on what nutrient forms the basis of the FU. It is thus impossible to draw general conclusions on the integrated sustainability of products based on this approach.

In the literature, protein has been the most commonly used individual nutrient as a basis for FUs (g or kg of protein) in food LCA studies (e.g. Sonesson et al., 2017). Protein is undeniably a very important nutrient globally; the environmental impacts of animal-based products rich in protein are among the highest, and the intake of protein is insufficient in many parts of the world. Furthermore, the role of protein is also crucial in the recent trend towards more plant-based or even vegan diets to minimize the environmental impact caused by food consumption. However, I suggest that even the intake of protein should not be used as a basis for a comparison as it ignores many important aspects of nutrition. There are some nutritional risks in the dietary shift towards the vegan diet. For example, in Finland, the long-term consumption of a vegan diet has been associated with lowered concentrations of some key nutrients in laboratory measured blood samples compared to reference values such as vitamins B12 and D, iodine and selenium (Elorinne et al., 2016). This indicates that a wider range of nutrients should be taken into account than just protein. In contrast, vegans showed more favourable fatty acid profiles, and concentrations of some polyphenols and eicosapentaenoic acid. The individual nutrient approach (as used in this dissertation) can be applied to these nutrients to determine the most eco-efficient means to ensure a sufficient intake of these sensitive nutrients. In the end, I assume that it may be sensible to consume a moderate amount of foods associated with high environmental impacts to ensure an intake of essential nutrients. Also Drewnowski (2015), and Tilman and Clark (2014) have highlighted this issue.

6.3.3 DISTINGUISHING BETWEEN SUSTAINABLE AND UNSUSTAINABLE PRODUCTS BY USING GWP/NUTRIENT INDEX AND LIM MEASURES

In the end, if/as it is the aim to define sustainable food products, it is also crucial to incorporate nutrients to be restricted in the assessment. I did it by using a separate measure, LIM index, for nutrients to be restricted in parallel with using nutrient index for recommended nutrients as FU, i.e. not including harmful nutrient in the initial FU (Figures 6 and 7). By including these three measures on the environmental impacts, and recommended and restricted nutrients, information on the negative environmental and nutrition/health impacts and the general nutritional quality of food as a positive function can be taken into account in the consideration. With this approach, it can be determined which products could, in general, be included in a sustainable diet. In this methodology, limit values for the LCA score (per nutrient index unit) and for the LIM index score must be set.

In parallel to the suggestion on using the $FNI_{prot}7$ product-group-specific nutrient index as an FU, I suggest the use of $FNI_{prot}7$ and LIM2 for distinguishing sustainable and unsustainable protein sources. The NR9 and LIM3 indexes can basically be used for all products, but regarding the raw-materials for food, this comparison is more theoretical, because it compares all kinds of products with each other regardless their functionality in the context of diet or consumer behaviour. Thus, it is not quite as suitable for consumer education or labels on the products or shelves in shops as a product-group-specific index. These general indexes are more suitable for sustainability comparison within ready-to-eat products which consist of protein sources and other types of ingredients.

This method does not include harmful substances other than nutrients to be limited, although these may occur in food products, such as chemical residues. Chemical residues can be assessed based on the established human toxicity impact category in the LCA (Rosenbaum et al., 2008), but there is not an established method to assess the impact of chemical residues combined with nutrients. To my knowledge, this kind of assessment has not been done. Human toxicity is a kind of endpoint impact indicator as such, assessing the impact of several chemicals and other substances emitted during the life cycle of a product on human health, but when the impacts of food are assessed, the assessment would be even more exhaustive if the impact of harmful nutrients would also be considered. This is a very topical issue, because current nutrition science is quickly developing and raising novel questions, e.g. how different substances and environmental chemicals affect the human genome (Alissa and Fwerns, 2017) and indirectly human health. Instead of widening the range of substances affecting human health, Stylianou et al. (2016) used the endpoint impact indicator in which even the environmental impacts are subordinate to the health impacts, i.e. they are one source of health impact, not an independent impact. However, environmental consideration could also be linked to their approach by using another endpoint indicator for these impacts, i.e. ecosystem health.

In contrast to my methodological choices, Doran-Browne et al. (2015) utilized an index consisting of both recommended and restricted nutrients as FU, namely NRF9-3 (Fulgoni et al., 2009). They compared it with other metrics, namely t CO_2e/t product, t CO_2e/t protein and t CO_2e/GJ. Despite the different methodological choice they also concluded, that the emissions/unit nutrient density (t CO_2e/unit nutrient density) was the preferred metric. They also pointed out that: "The metric emissions/unit nutrient density has the potential to inform consumer choices regarding foods that have a higher nutritional content compared with the GHGE (greenhouse gas emissions) generated, assuming this metric can be presented to consumers in a clear manner that is easy for consumers to understand." These conclusions are basically parallel to my results, but there is still a fundamental discrepancy. The products in their study were defined as "saleable products", for example lean beef, and thus, the products were not "eatable products". Nutrient indexes consisting of recommended and restricted nutrients easily confer a negative value for eatable foods, and thus they are not suitable for use as an FU. In the work by Doran-Browne et al. (2015) negative values apparently did not occur. This was probably because of a system boundary, but it is not a certainty because the calculation details were not sufficiently described in their article.

6.4 WHAT PRECONDITIONS AND CHALLENGES DOES AN ASSESSMENT HAVE WHEN THESE APPROACHES ARE APPLIED?

6.4.1 SYSTEM BOUNDARIES AND BIO-WASTE

The system boundaries of LCAs can be challenging when the entire life cycle until the consumption phase is considered. Bio-waste, particularly household waste and leftovers, can affect the nutritional service of products. Waste from the production chain affecting environmental performance can quite easily and reliably be incorporated into the material flow analysis forming a basis for an LCA, but how can household waste and leftovers be taken into account? Household waste particularly affects the environmental impact of food, while plate leftovers affect both the environmental and the nutritional impact.

It seems that the amount of household waste varies between foods: more waste from vegetables than meat products, for example (Silvennoinen et al., 2014). Should this waste be included in the environmental impact of a product, or should it be considered separately (as an impact assessment of consumption patterns or household practises)? This naturally depends on a scope of the study.

Theoretically, two types of bio-waste flows there can be divided: (at least almost) unavoidable and avoidable bio-waste. Unavoidable bio-waste refers to flows that are produced in minimum to provide (guarantee) the food service in question, for example pan or pot leftovers. Avoidable bio-waste relates more to insufficient management and unconcerned or routinized habits. For example plate leftovers can be either of them.

I suggest that unavoidable bio-waste flows should always be included in the environmental impact assessment of a product (or portion), at least. However, this flow does not provide a nutritional service, because it is not or will not be eaten, and thus, I suggest, nutrients that are included in this flow should not be included in a nutritional FU.

Avoidable bio-waste is more complicated issue. Depending on the scope of the study, they may be sensible to be included in the impact assessment of a product in a case study in the same way than unavoidable bio-waste. This means that the life cycle of the product would be completed by consumption phase. On the other hand, they might be sensible to be separated from the "nutritional service" (meaning intake of nutrients, eating) to be a part of "food provision" (meaning practises to get food for eating), for example, if the scope of the study is to consider the environmental impacts of various household practices. This kind of separation is challenging, but would be beneficial to be carried out so that possibilities for environmental improvement would be revealed. In any case, nutrients in bio-waste should of course not be included in nutritional FU, because they are not eaten.

In this dissertation, household waste is not included in the LCAs of the case products or meals, with the exception of school meals in Article II where bio-waste in a canteen was included. However, the share of bio-waste from the environmental impacts of school meals was not analysed. It would require further research to determine how much the inclusion of bio-waste in different circumstances would affect the results.

6.4.2 A NEED TO IDENTIFY THE REFERENCE FLOW

According to the test calculation, defining a reference flow (RF) is crucial when an index approach is applied because the nutrient index score uses as FU does not directly imply a quantity of a product. The RF, however, describes a quantity of the product needed to provide a unit of the nutrient index. Given that the quantity of food relates to the every-day life of consumers and is easy to understand, the RF makes the final environmental impact/nutrient index scores easier to understand and compare to the scores of other products. It is important to show both of these measures, the environmental impact/nutrient index and the RF for unit of nutrient index. In comparison, currently in the most commonly applied LCA practice, i.e. the use of mass-based FUs, the quantity of food is obvious as it is equal to the FU. In the interpretation of the results, the RF alongside the environmental impact/nutrient index could alter conclusions; a lower RF could, to some extent, compensate for a high environmental impact/nutrient index score because a smaller amount of food would be needed to fulfil a nutritional recommendation, and vice versa, a higher RF could reduce the significance of a low environmental impact/nutrient index score. In addition, the identification of an RF makes it possible to calculate the LIM index for a food to be integrated with a score from the environmental impact/nutrient index. Thus, the RF has a very important role in drawing up the final results and conclusions on the sustainability of food products.

It is equally, or even more, important to use an RF in a case using a mass unit as an FU for individual nutrients. In this context a product with a very low environmental impact per kg and a low content of the nutrient at hand could incur a substantially low score for the environmental impact per mass-unit of the nutrient. The product could however be only a poor source of that nutrient, and thus the nutrient would need to be obtained from a very large amount of that product or other source. Thus, the product does not necessarily have an actual environmental benefit compared to other products. To avoid this kind of misinterpretation, it is necessary to offer information on the portion size. This can be done by providing an RF for the DRI. This measure describes how large an amount of a product would be needed to fulfil the daily recommended intake for the nutrient at hand. The interpretation of an RF as a sensible portion is, however, not straightforward. In the interpretation, it should be taken into account that potentially there are also other sources for that nutrient and that typical portion sizes vary among the foods.

6.4.3 DATA QUALITY REQUIREMENTS

Based on evaluation and test calculations, data quality is one of the preconditions for and challenges in achieving good quality LCA applications linking nutrition into the assessment. I suggest that data on nutrition, particularly the nutrient content of a product, should be level with the activity data for environmental assessment for the sake of accuracy. According to the LCA standards (ISO14040:2006; ISO 14044:2006), primary data (i.e. chain-specific data) should be emphasized particularly regarding phases of the production chain which are responsible for the main environmental impacts. For example, the ILCD (EC/JRC, 2010) follows this rule by requiring the use of primary data on primary production in food LCAs, from which most environmental impacts originate. In contrast to this, more practical guidelines, such as the PAS2050 and product category rules (PCRs) related to environmental product declaration (EPD) systems, often require the use of primary data related to core processes (i.e. phases that are under the direct control of the LCA practitioner/orderer), but the use of secondary data (general data from databases and statistics, for example) is often allowed for other phases of the life cycle of the product – regardless of their contribution to the environmental impacts of the product. This is based more on practicality than methodological relevance, or validity.

In addition, according to the LCA standards (ISO14040:2006; ISO 14044:2006), the data requirements in an LCA application should be set according to the scope of the study. In my view primary and secondary data could both be used but in different kinds of studies. A study for supporting policy-making would be based on national statistics etc., while assessing the environmental performance of a certain product in a specific production chain should be based on primary data from that chain and for the nutritional performance based on that product. In that sense, when doing an assessment for a certain product I suggest, the nutrient content of a product should be determined based on laboratory measurements of a product, not based on database. Data from databases should be used with caution, because the manner of production, cultivation variety and climate, for example, affect the nutritional quality of agricultural products. These also influence the data in national nutrient databases. It may seem that food composition databases, such as Fineli® in Finland, include product-specific data, but much of this data is based on calculations, not on laboratory analysis of the actual products. Thus, choices between practices or inputs in the production chain do not necessarily affect the nutrient content figures. Data from databases can, instead, safely be used in more general applications referring to average products, for example.

The methodologies introduced in this dissertation can be applied in a general level assessment based on secondary data and a production-chain-specific assessment based on primary data. It is, however, important that the primary data should be used for the nutritional data if the assessment is done on the product-specific level, as is said above. This kind of assessment relates typically, for example, product labelling.

It should be noted that I used data from the Fineli® (THL, 2017) food composition database in my test calculations. Thus, the results are not necessarily compatible with the actual products from the specific production chains.

6.5 DO DIFFERENT APPROACHES RESULT IN DIFFERENT OUTCOMES AND INTERPRETATION OF THE CLIMATE IMPACT OF FOOD PRODUCTS?

In Table 12, there is a summary of the results for a set of products based on the different product-level approaches to provide an insight into how the different approaches result in differing outcomes and interpretations. In Table 10 instead, there is a summary of results for a set of meals based on a standardised lunch as an FU.

In the literature as well as the common scientific and popular discourse, the message has been clear when reasoning for sustainable food consumption and sustainable food products: one should avoid meat and other animal-based foods, particularly beef, because beef has by far the greatest environmental impact and plant-based protein rich products are substantially less of an environmental burden (e.g. Carlsson-Kanyama and Gonzalez, 2009; Notarnicola et al., 2017b; Steinfeld et al., 2006). Thus, red meat, particularly beef and also milk products could be defined as unsustainable (in contrast to sustainable products). Additionally, nutrition recommendations have encouraged consumers to shift towards more plant-based foods, and particularly to restrict red mead (i.e. beef, mutton, pork etc.). Some nutritionists have however raised questions concerning whether this orientation risks an intake of some essential nutrients on average or in relation to special-groups of consumers (e.g. Buttriss and Riley, 2013). Well, does it? Basically, the question calls for an assessment of environmental impacts and nutrient content on a dietary scale (see e.g. Payne et al., 2016), but the product scale methods introduced in this dissertation can also help answer the question.

6.5.1 INFLUENCE OF USING INDIVIDUAL NUTRIENT - OR NUTRIENT INDEX -BASED FU

According to the data, beef and mutton have the largest GWP per 100 g of product, followed by other animal-based products, except eggs and rainbow trout (which is cultivated fish). Plant-based products and particularly wild fish have the lowest GWP (Table 12). According to the results, by using the nutrient index $FNI_{prot}7$, beef and mutton do better in relation to other animal-based products. Emmental cheese, with a relatively high fat content, has the largest GWP per unit for the nutrient index, while nuts, beans and seeds and particularly wild fish have again the lowest GWP. However, looking at the reference flows (RF) in Table 12, it can be seen that these vary considerably between products within the products groups 1) meat, cheese and eggs, 2) fish and 3) nuts, beans and seeds. The RF shows how large a quantity of a product is needed to get one unit of the nutrient index for the product. In other words, it describes the nutrient density of a product: the higher the RF is the less nutrient dense the product is (in relation to nutrients included in the nutrient index at hand). In principle, the best product in terms of its nutrient content compared to its climate impact has the lowest GWP per unit of the nutrient index and the lowest RF, while the worst product in terms of its nutrient content compared to its climate impact has the largest GWP and the highest RF. So, based on that, hemp seed might be the best product and Emmental cheese certainly is the worst product in terms of its nutrient content compared to its climate impact in Table 12, but it would need further research to fully understand the whole picture.

Furthermore, I claim that the reference amount (RA, g) for the daily recommended intake (DRI) is a very important factor when analysing GWPs per mass-based unit for single nutrients. For example, the Baltic herring is by far the best source of vitamin B12 taking both GWP and RA into account. Notably, plant-based products do not contain vitamin B12, and so they are the least eco-efficient sources of it. Other wild fish foods, instead, also do well as 90 g for a daily intake is very reasonable (particularly compared to other sources, for example broiler slices). Interestingly broiler does well with vitamin B12 compared to beef, but poorly with Fe. Hemp seeds are the most effective source of Fe, but the question is, whether 110 g is a suitable portion for hemp seed. The answer obviously depends on the individual diet.

Finally, comparing the GWP and related RA for products in relation to protein it can be seen that beef is a good source of protein with its lowest RA, but it has the highest GWP per gram of protein (Table 12). For comparison, the lowest GWP per gram of protein is for wild fish foods. The RAs for fish range between 420 and 530, which are rather high but still acceptable as protein is not a rare nutrient, as there are plenty of sources of proteins. Nevertheless, the conclusion about which products should be included in a sustainable diet is not self-evident based on these results. It would require an assessment on a dietary scale. I highlight that a product scale comparison should be made with caution, and never solely based on the GWP per any of the mass-based units.

When drawing conclusions, it is notable however that the beef model applied in the study was based on combined production, which is a much more efficient method than specialised beef production. For comparison, the GWP for Finnish beef from specialised production is approximately 5.51 kg CO_2-eq per 100 g (screening based on data from Saarinen et al. (2016)), which is a little bit high compared to the values presented in the literature, but still in accordance with the highest published values (de Vries et al., 2015). With such a large GWP, beef from specialised production has by far the highest climate impact regardless of the FU, assuming that the nutrient content would be equal regardless of the source of feed. This detail, however, highlights reduction potential relates to production practices particularly linked to animal-based foods which currently have high environmental impacts in several impact categories.

6.5.2 INFLUENCE OF USING METHOD TO DEFINE SUSTAINABLE PRODUCTS AND STANDARDISED LUNCH

There are two points where a product-group-specific method to distinguishing sustainable and unsustainable products produces results that clearly vary from common claims: these are for wild fish and beef (Figure 6). Wild fish is usually regarded as both an eco-friendly and healthy food. Dishes made from wild fish have low GWP/FNIprot7 scores also in this dissertation, but interestingly many of them have the highest scores for the LIM2 index (Table 12). Thus they are the most unsustainable in the range of products assessed in this dissertation in relation to harmful nutrients. In this context, the preparation manner greatly affects the results, for instance frying in butter has a severely negative impact on the scores. If wild fish foods had been fried with vegetable oil or prepared in another way without using any fat for frying, the final results would have been much better, and probably these fish dishes would have been identified as sustainable food products. In this dissertation, frying in butter was chosen as the preparation manner for wild fish, because it is a typical way to prepare wild fish as a food in Finland. It is valued very highly in Finnish cuisine. However, these results for fish foods highlight the importance of also taking the preparation phase into account.

In contrast to a common claim, fried beef may even be regarded as a sustainable food product when the assessment method based on product-group-specific nutrient indexes is used (Figure 6). Indeed, it does not have the highest score for the GWP per nutrient index unit (Table 12). These are new insights into the sustainability of food. The conclusion is however very sensitive to the thresholds set for the GWP per nutrient index unit and the

LIM index, and values for the GWP per kg of various products is discussed in the previous section regarding the production manner of beef.

According to the results above, it is clear that beef particularly, in addition to hemp seeds, Hazelnuts and soybeans, would benefit from the inclusion of nutrition criteria in food LCA on a product scale. The same issue can partly be seen at a more general level also on the portion scale, where nutrition is included in the food LCA in a different manner. Mixed home-made lunches resulted in just 2-6 times more potential climate and eutrophication impacts than vegetarian and vegan lunches (Table 10). In comparison, the climate impact of beef is 15-fold compared to soybeans (without impacts from land use change) as an uncooked food ingredient in a kilo-basis assessment (Saarinen et al., 2011).

According to the assessment on the portion scale, the choice of salad also makes a substantial difference from the point of view of the climate impact due to greenhouse production compared to outdoor production (Table 10). The choice of starch, even rice, was without major implications in the context of the plate model, due mostly to variation in (typical) portion sizes. These issues are rarely reported in the literature in the context of meals, or eatable products, i.e. food in a cooked form.

Based on these results, on one hand, including the product system until an eatable product is produced, including the preparation phase is crucially important. On other hand it is equally important to include a combination of foods with different roles in nutrition in the assessment so that the whole picture of the climate impact can be seen. The implications of this aspect should be investigated in more detail on a diet scale: i.e. to what extent beef and other products with high climate impacts and a high nutritional value per kg are relevant for inclusion in the sustainable diet. Diet optimization by linear programming is one option for doing this, and this has already been seen in some studies (Gephart et al., 2016; Song et al., 2017; Tyszler et al., 2014).

Furthermore, the ready-to-eat lunches in this study resulted interestingly in less potential impact on the climate than the equivalent home-made lunches more because of raw material choices than energy consumption (Table 10). This is in accordance with the study by Rivera et al. (2014). We may live in a world where economies of scale are already being exceeded, at least from the point of view of the environment impacts, but it may also reflect the situation with (direct) economic benefits as well, because eco-efficiency is often in accordance with economic efficiency. This area would need further research regarding the use of resources, the environment and nutrition (nutrient contents of foods processed in different ways).

7 CONCLUSIONS

7.1 GENERAL CONCLUSIONS

The analysis in this dissertation supports the hypothesis "Nutrition can be taken into account in the food LCA on the product and the portion scales so that relevant additional information can be achieved compared to the current LCA practice". The main conclusion is that nutrition can, and also should, be taken into account in versatile ways in the food LCA. It should be done on every scale of consideration and by a manner depending on the scope and goal of the study.

The dissertation studied different ways to link nutrition into the food LCA on the product and portion scales. It introduced new promising methods to achieve this on both scales. The new methods are based on 1) the nutrient indexes and 2) the lunch plate model with a specification of nutritional quality based on nutrient recommendations. These were used as FUs. In addition, an approach with 3) mass-based FUs for individual nutrients was analysed. Each assessment manner has its own strength, and vice versa none of the methods can provide an all-inclusive understanding.

In particular, the nutrient index approach introduced is new and unique. It combines a nutrient index based on recommended nutrients used as an FU considering an RF with the results from an environmental impact/nutrient index assessment and the separate use of a nutrient index based on restricted nutrients (the LIM indexes). By carrying out this assessment, sustainable food products can be distinguished from unsustainable ones.

The approach based on the use of the plate model, with a specification of nutritional quality based on nutrient recommendations, used as an FU is also unique. This is usable particularly in general sustainability education for consumers, and it could be developed further to be applied also in personal nutrition and sustainability counselling in respect of food consumption.

To my knowledge, the use of mass-based FUs for individual nutrients is evaluated extensively for the first time in this dissertation. Previously, it has been only occasionally applied to some nutrients, particularly to protein, but not to a range of nutrients. An advantage of the approach is particularly in that it can be used to identify the most eco-efficient sources of scarce nutrients, such as vitamin B12 or Fe. It might be able to be utilized also in the assessment of eco-efficiency sources of EAAs.

Dealing with the linkage between nutrition and the environmental impacts on a product and meal scale is relevant from the point of view of making a purchasing decision. The approaches are also linked to the diet level by specific features of the methods or on a knowledge-basis. However, to gain an overall picture of the nutrition, health and the environmental impacts of food consumption, a comprehensive assessment on a dietary scale is needed.

Interaction and cooperation between environmental and nutrition specialists will play a crucial role in the development of an integrative method to link nutritional aspects into a food LCA. In this dissertation this has been achieved by involving two nutrition professors (with expertise in public health and food chemistry) in the development of the index approach, and a consumer scientist in the development process of the plate model approach, alongside environmental and life cycle specialists. This fruitful interaction has had a remarkable influence on the developed methods. For example, in the index approach, from the point of view of nutrition science, a nutrient index consisting of recommended and restricted nutrients is a basic starting point, but from the LCA point of view it is sensible to separate these aspects into two different indexes, because one of them represents a benefit from the consumption of a product and the other represents in turn a disadvantage. Regarding the standardised lunch, the theories of practice from consumer science was the starting point for the study. According to it, the consumer education should be anchored in the everyday life of the consumer, and thus the plate model was selected as the basis for an FU.

Interaction between environmental, nutrition and food science is crucial also in the further development of food LCA methods. Nutrition science constantly produces new and more precise knowledge about human nutritional needs, as well as the impact of various nutrients and other food components on human health. Food science, in turn, provides new and more precise knowledge on nutrients and other component of various food items. Some of these can affect human health so much that they should be included in the FUs, if they are beneficial to health. This can be done either alone (in the individual nutrient approach) or together with other components (in the index approach). In the case of harmful components, these should be considered separately as has been done in this dissertation. Food science also produces new food ingredients, for example, from the side flows of the food and other industries. Foods containing these ingredients have potentially different health and the environmental impacts than existing foods.

I focused mainly on products and meals in this dissertation. However, the diet is the most important level from the point of view of public health and consumers in the sense that the health impacts caused by nutrition emerge only in the context of the entire diet. In the same way, the environmental impacts of food consumption should be considered on a dietary scale because the environmental impacts are relevant only on large scale. However, food choices are made at a product and meal level, and thus it is sensible and relevant to provide information at that level.

7.2 FUTURE RESEARCH

There are still several issues to be dealt with in linking the environmental and nutritional aspects of food in sustainability assessments. These aspects relate to product scale, meal scale and diet scale assessments.

In product scale assessments, the methodology developed and tested in this dissertation should be applied more widely to protein sources using accurate data and a wider range of impact categories to ensure the applicability of the methodology. In addition, the corresponding product-group-specific approach should be developed, validated and applied also to an LCA for other product groups. The composition of product-group-specific indexes should be elaborated from the point of view of amino acids in protein sources and secondary metabolites for vegetables, fruits and berries, for example. In this development, the question is what level of nutrient composition in the nutrient index can sufficiently differentiate products within product groups, taking both the nutritional value and environmental impacts into account. The composition of such indexes, and also general nutrient indexes, should always be based on the state of public nutrition if the index is to be used in consumer education with the aim of steering the consumption of food in a particular direction. The nutrient index should consist of the most important nutrients for the product group, but also highlight nutrients whose intake is at an insufficient level. In some circumstances some weighting might also provide opportunities to balance different nutrients in the nutrient index. Currently the most used nutrient indexes are based on the equal weighting of different nutrients, but in fact, nutrients are not equally important in respect to human health, at least in a short time span. For example, a deficiency of protein causes more severe impacts in general than some micronutrients. In Western societies, protein deficiency hardly exists, but in some other parts of the world deficiency of protein is a severe problem. These issues should be addressed in future research.

In respect to identifying sustainable food products, there are two main issues to be addressed in future developments. First, it is important to set a threshold value for the environmental impact/nutrient index values and LIM values. In this dissertation, tentative threshold values for the GWP/nutrient index and for LIM/RF(nutrient index) were set, but these should be critically evaluated in future research, as presented in Section 4.5, and robust thresholds should be set by interdisciplinary collaboration.

Furthermore, the approach of using mass-based FUs for individual nutrients should be evaluated further. The approach might also be possible to utilize in the assessment of eco-efficiency sources of EAAs or secondary metabolites, for example.

Regarding a meal scale assessment, the use of the general nutrient index for meals and convenience products (ready-to-eat meals) which consist of protein sources and other types of ingredients should be evaluated. I assume this would be particularly applicable because meals typically include a wider set of nutrients than individual products and thus they should also meet nutrition requirements at a more general level. In future research, this approach should be evaluated also in relation to the plate model.

Finally, there is still a need for further research on the environmental impacts related to foods to replace or complement meat and other animal-based products, also in the context of diet. Thus, there is currently a lot of research going on internationally into dietary level impact assessments, including the environmental, the nutrition and the health impacts, and such research should be ongoing in Finland, too. Among other crucial issues, also in research on a dietary scale, it is important to include the product system required to achieve eatable products, including the preparation phase, so that all the ingredients and energy use are taken into account.

REFERENCES

Alissa, E. M., Ferns, G. A. 2017. Dietary fruits and vegetables and cardiovascular diseases risk. Crit Reviews in Food Sci and Nutr 57, 9, 1950-1962, DOI 10.1080/10408398.2015.1040487.

Amani, P., Schiefer, G. 2011. Review on Suitability of Available LCIA Methodologies for Assessing Environmental Impact of the Food Sector. Int J Food Syst Dynamics 2, 2, 194-206. DOI 10. 18461/ijfsd.v2i2.228.

Amienyo, D., Gujba, H., Stichnothe, H., Azapagic, A. 2013. Life cycle environmental impacts of carbonated soft drinks. Int J Life Cycle Assess 18, 77–92. DOI 10.1007/s11367-012-0459-y.

Arambepola, C., Scarborough, P., Rayner, M. 2008. Validating a nutrient profile model. Public Health Nutr 11, 371–8. DOI:10.1017/S1368980007000377.

Avadí, A., Fréon, P., Quispe, I. 2013. Environmental assessment of Peruvian anchoveta food products: is less refined better? Int J Life Cycle Assess 19, 1276–1293. DOI 10.1007/s11367-014-0737-y.

Azais-Braesco, V., Goffi, C., Labouze, E. 2006. Nutrient profiling: comparison and critical analysis of existing systems. Public Health Nutr 9, 5, 613–22.

Baldini, C., Gardoni, D., Guarino, M. 2017. A critical review of the recent evolution of Life Cycle Assessment applied to milk production. Review. J Cleaner Prod 140, 421-435. DOI 10.1016/j.jclepro.2016.06.078.

Bare, J., Gloria, T. P. 2008. Environmental impact assessment taxonomy providing comprehensive coverage of midpoints, endpoints, damages, and areas of protection. J Cleaner Prod 16, 10, 1021–1035. DOI 10.1016/j.jclepro.2007.06.001.

Bare, J. C., Hofstetter, P., Pennington, D. W., Udo de Haes, H. A. 2000. Midpoints versus Endpoints: The Sacrifices and Benefits. Life Cycle Impact Assessment Workshop Summary. Int J Life Cycle Assess 5, 6, 319 – 326. DOI 10.1007/BF02978665.

Becker, W., Lyhne, N., Pedersen, A. N., Aro, A., Fogelholm, M., Phorsdottir, I., Alexander, J., Anderssen, S. A., Meltzer, H. M., Pedersen, J. I. 2004. Nordic Nutrition Recommendations 2004 - integrating nutrition and physical activity, Scand J Nutr 48:4, 178-187. DOI 10.1080/ 11026480410003794

Brankatschk, G., Finkbeiner, M. 2015. Modeling crop rotation in agricultural LCAs — Challenges and potential solutions. Agric Systems 138, 66–76. DOI 10.1016/j.agsy.2015.05.008.

Bryngelsson, D., Wirsenius, S., Hedenus, F., Sonesson, U. 2016. How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. Food Policy 59, 152–164. DOI 10.1016/j.foodpol.2015.12.012.

Bushman, B. 2017. Understanding and Using the Dietary Guidelines for Americans. ACSM's Health & Fitness J. 21, 4, 4-8. DOI 10.1249/FIT.0000000000000258.

Buttriss, J., Riley, H. 2013. Sustainable diets: Harnessing the nutrition agenda. Food Chem 140, 402-407. DOI 10.1016/j.foodchem.2013.01.083.

Calderón, L. A., Iglesias, L., Laca, A., Herrero, M., Díaz, M. 2010. The utility of Life Cycle Assessment in the ready meal food industry. Resources, Conservation and Recycling 54, 1196–1207. DOI 10.1016/ j.resconrec.2010.03.015.

Camelon, K., Hådell, K., Jämsén, P., Ketonen, K., Kohtamäki, H. M., Mäkimatilla, S., Törmälä, M-L 1998. The Plate Model: A Visual Method of Teaching Meal Planning. J A Diet Assoc 98, 10, 1155–1158.

Carlsson-Kanyama, A. 1998. Climate change and dietary choices — how can emissions of greenhouse gases from food consumption be reduced? Food Policy 23, 3/4, 277–293. DOI 10.1016/S0306-9192(98)00037-2.

Carlsson-Kanyama, A., Gonzalez, A. D. 2009. Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 89(suppl), 1704S–9S. DOI 10.3945/ajcn.2009.26736AA.

Cashion, T., Hornborg, S., Ziegler, F., Hognes, E. S., Tyedmers, P. 2016. Review and advancement of the marine biotic resource use metric in seafood LCAs: a case study of Norwegian salmon feed. Int J Life Cycle Assess 21, 1106–1120. DOI 10.1007/s11367-016-1092-y.

Cerutti, A. K., Bruun, S., Donno, D., Beccaro, G. L., Bounous, G.2013. Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. J Cleaner Prod 52, 245-252. DOI 10.1016/j.jclepro.2013.03.029.

Clay, W. D. 1997. Preparation and use of food-based dietary guidelines. FNA/ANA 19 1997.

Contento, I.R. 2008. Nutrition education: linking research, theory, and practice. Review Article. Asia Pac J Clin Nutr 17, 1, 176-179.

Darmon, N., Darmon, C., Maillot, M., Drewnowski, A., 2005. A nutrient density standard for vegetables and fruits: nutrients per calorie and nutrients per unit cost. J Am Diet Assoc 105, 1881e1887.

Darmon, N., Vieux, F., Maillot, M., Volatier, J-L., Martin, A. 2009. Nutrient profiles discriminate between foods according to their contribution to nutritionally adequate diets: a validation study using linear programming and the SAIN,LIM system. Am J Clin Nutr 89, 1227–36. DOI 10.3945/ajcn.2008.26465.

Davis, J., Sonesson, U. 2008. Life cycle assessment of integrated food chains—a Swedish case study of two chicken meals. Int J Life Cycle Assess 13, 574–584. DOI 10.1007/s11367-008-0031-y

Davis, J., Sonesson, U., Baumgartner, D.U, Nemecek, T. 2010. Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. Food Res Int 43, 1874–1884. DOI 10.1016/j.foodres.2009.08.017

de Boer, J., Helms, M., Aiking, H. 2006. Protein consumption and sustainability: Diet diversity in EU-15. Ecol Econ 59, 267-274. DOI 10.1016/ j.ecolecon.2005. 10.011

De Marco, I., Miranda, S., Riemma, S., Iannone, R. 2015. Environmental assessment of drying methods for the production of apple powders. Int J Life Cycle Assess 20,1659–1672. DOI 10.1007/s11367-015-0971-y

Derrien, M., van Hylckama Vlieg, J. E. T. 2015. Fate, activity, and impact of ingested bacteria within the human gut microbiota. Review. Trends in Microbiol 23, 6. DOI 10.1016/j.tim.2015.03.002.

de Vries, M., vanMiddelaar, C. E., deBoer, I. J. M. 2015. Comparing environmental impacts of beef production systems: A review of life cycle assessments. Livestock Sci 178,279–288. DOI 10.1016/j.livsci.2015.06.020.

Donati, M., Menozzi, D., Zighetti, C., Rosi, A., Zinetti, A., Scazzina, F. 2016. Towards a sustainable diet combining economic, environmental and nutritional objectives. Appetite 106, 48-57. DOI 10.1016/j.appet.2016.02.151.

Doran-Browne, N. A., Eckard, R. J., Behrendt, R., Kingwell, R. S. 2015. Nutrient density as a metric for comparing greenhouse gas emissions from food production. Climatic Change 129, 73–87. DOI 10.1007/s10584-014-1316-8.

Draaisma, R. B., Wijffels, R. H., Slegers, P. M., Brentner, L. B., Roy, A., Barbosa, M. J. 2013. Food commodities from microalgae. Current Opin in Biotechn 24,169–177. DOI 10.1016/j.copbio.2012.09.012.

Drewnowski, A., 2005. Concept of a nutritious food: toward a nutrient density score. Am J Clin Nutr 82, 721-732.

Drewnowski, A., 2010. The nutrient rich foods index helps to identify healthy, affordable foods. Am J Clin Nutr 91 (Suppl. l.), 1095S-101S.

Drewnowski, A. 2015. Energy and nutrient density of foods in relation to their carbon footprint. Am J Clin Nutr 101,184–91. DOI 10.3945/ajcn.114.092486.

Drewnowski, A., Fulgoni III, V., 2008. Nutrient profiling of foods: creating a nutrient-rich food index. Nutr Rev® 66, 1, 23-39.

Drewnowski, A., Fulgoni VL. 2014. Nutrient density: principles and evaluation tools. Am J Clin Nutr 99, 1223S–1228S. DOI 10.3945/ajcn.113.073395.

Dubois, V., Breton, S., Linder, M., Fanni, J., Parmentier, M. 2007. Fatty acid profiles of 80 vegetable oils with regard to their nutritional potential. Eur J Lipid Sci Technol, 109: 710-732. DOI 10.1002/ejlt.200700040.

Earles, J. M., Halog, A. 2011. Consequential life cycle assessment: a review. Int J Life Cycle Assess 16, 445–453. DOI 10.1007/s11367-011-0275-9.

EFSA, 2017. Dietary reference values and dietary guidelines http:// www.efsa.europa.eu/en/topics/topic/dietary-reference-values-and-dietary-guidelines. Visited 4-21-2017.

Elorinne, AL., Alfthan, G., Erlund, I., Kivimäki, H., Paju, A., et al. 2016. Food and Nutrient Intake and Nutritional Status of Finnish Vegans and Non-

Vegetarians. PLOS ONE 11(2): e0148235. DOI 10.1371/journal.pone.0148235.

EC/JRC, 2010. International Reference Life Cycle Data System (ILCD) Handbook - Framework and Requirements for Life Cycle Impact Assessment Models and Indicators. First edition March 2010. Publications Office of the European Union. Available at http://eplca.jrc.ec.europa.eu/?page_id=86. Visited 4-24-2017.

EU, 2016. Sustainable Food. European Commission. http://ec.europa.eu/environment/archives/eussd/food.htm. Visited 4-24-2017.

FAO, 2010. Dietary guidelines and sustainability. Available at http://www.fao.org/nutrition/education/food-dietary-guidelines/background/sustainable-dietary-guidelines/en/. Visited 1-3-2018

FAO, 2017a. Key facts and findings. http://www.fao.org/news/story/en/item/197623/icode/. Visited 05-29-2017.

FAO, 2017b. Greenhouse Gas Emissions from Agriculture, Forestry and Other Land Use. http://www.fao.org/resources/infographics/infographics-details/en/c/218650/. Visited 05-29-2017.

Figueiredo, F., Castanheira, E. G., Freire, F. 2017. Life-cycle assessment of irrigated and rainfed sunflower addressing uncertainty and land use change scenarios. J Cleaner Prod 140, 436-444. DOI 10.1016/j.jclepro.2016.06.151.

Fischer, C. G., Garnett, T. 2016. Plates, pyramids and planets - Developments in national healthy and sustainable dietary guidelines: a state of play assessment. FAO and The Food Climate Research Network at The University of Oxford. ISBN 978-92-5-109222-4.

Fogelholm, M. 2013. New Nordic Nutrition Recommendations are here. Food Nutr Res 57. DOI 10.3402/fnr.v57i0.22903.

Fogelholm, M. 2016. Nutrition recommendations and science: next parallel steps. J Sci Food Agric 96, 1059–1063. DOI 10.1002/jsfa.7479.

Friel, S., Barosh, L. J., Lawrence, M. 2013. Towards healthy and sustainable food consumption: an Australian case study. Public Health Nutr 17,5, 1156–1166. DOI 10.1017/S1368980013001523

Fulgoni, V. L., Keast, D.R., Drewnowski, A., 2009. Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods. J Nutr 139, 1549-1554. DOI 10.3945/jn.108.101360.

Garnett, T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36, S23-S32. DOI 10.1016/j.foodpol.2010.10.010.

Garnett, T. 2014. What is a sustainable healthy diet? A discussion paper. Food Climate Research Network. Available at www.fcrn.org.uk.

Gephart, J. A., Davis, K. F., Emerya, K. A., Leach, A. M., Galloway, J. N., Pace, M. L. 2016. The environmental cost of subsistence: Optimizing diets to minimize footprints. Sci Total Environ 553, 120–127. DOI 10.1016/j.scitotenv.2016.02.050.

Goglio P., Brankatschk G., Trydeman Knudsen M., Williams A.G., Nemecek T., 2017. Addressing crop interactions within cropping systems in LCA. Int J Life Cycle Assess., DOI 10.1007/s11367-017-1393-9, 9p.

Goldstein, B., Hansen, S. F., Gjerris, M., Laurent, A., Birkved, M. 2016. Ethical aspects of life cycle assessments of diets. Food Policy 59, 139–151. DOI 10.1016/j.foodpol.2016.01.006.

Groen, E.A, Heijungs, R. 2017. Ignoring correlation in uncertainty and sensitivity analysis in life cycle assessment: what is the risk? Environ Impact Assess Rev 62, 98–109. DOI 10.1016/j.eiar.2016.10.006.

Guenther, P.M., Casavale, K.O., Reedy, J., Kirkpatrick, S.I., Hiza, H.A.B., Kuczynski, K.J., Kahle, L.L., Krebs-Smith, S.M. 2013. Update of the Healthy Eating Index: HEI-2010. J Acad Nutr and Diet 113, 4. DOI 10.1016/j.jand.2012.12.016.

Gutierrez, M. M., Meleddu, M., Piga, A. 2017. Food losses, shelf life extension and environmental impact of a packaged cheesecake: A life cycle assessment. Food Res Int 91, 124–132. DOI 10.1016/j.foodres.2016.11.031.

Guo, M., Murphy, R. J. 2012. LCA data quality: Sensitivity and uncertainty analysis. Sci Total Environ 435–436, 230–243. DOI 10.1016/ j.scitotenv.2012.07.006.

Hadjikakou, M. 2017. Trimming the excess: environmental impacts of discretionary food consumption in Australia. Ecol Econ 131, 119–128. DOI 10.1016/j.ecolecon.2016.08.006

Halloran, A., Roos, N., Eilenberg, J., Cerutti, A., Bruun, S. 2016. Life cycle assessment of edible insects for food protein: a review. Agron Sustain Dev 36, 57. DOI 10.1007/s13593-016-0392-8.

Hallström, E., Carlsson-Kanyama, A., Börjesson, P. 2015. Environmental impact of dietary change: a systematic review. J Cleaner Prod 91, 1-11. DOI 10.1016/j.jclepro.2014.12.008.

Hanssen, O. J., Vold, M., Schakenda, V., Tufte, P-A., Møller, H., Olsen, N. V., Skaret, J. 2017. Environmental profile, packaging intensity and food waste generation for three types of dinner meals. J Cleaner Prod 142, 395-402. DOI 10.1016/j.jclepro.2015.12.012.

Harland, J. I., Buttriss, J., Gibson S. 2012. Achieving *eatwell plate* recommendations: is this a route to improving both sustainability and healthy eating? British Nutrition Foundation. Nutr Bull 37, 324–343. DOI 10.1111/j.1467-3010.2012.01988.x

Hawkes, C. 2013. Promoting healthy diets through nutrition education and changes in the food environment: an international review of actions and their effectiveness. Rome: Nutrition Education and Consumer Awareness Group, Food and Agriculture Organization of the United Nations. Available at http://www.fao.org/docrep/017/i3235e/i3235e.pdf.

Heijungs, R. and Huijbregts, M.A.J. 2004. A Review of Approaches to Treat Uncertainty in LCA. Int Congr on Enviro Modelling and Software 197. Available at https://scholarsarchive.byu.edu/iemssconference/2004/all/197.

Henchion, M., Hayes, M., Mullen A. M., Fenelon, M., Tiwari, B. 2017. Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. Foods 2017, 6, 53. DOI:10.3390/foods6070053

Hendrie, G. A., Ridoutt, B. G., Wiedmann, T. O., Noakes, M. 2014. Greenhouse Gas Emissions and the Australian Diet—Comparing Dietary Recommendations with Average Intakes. Nutrients 6, 289-303. DOI 10.3390/nu6010289.

HHS and USDA, 2015. Dietary Guidelines for Americans 2015–2020. 8th Edition. U.S. Department of Health and Human Services and U.S. Department of Agriculture. December 2015. Available at http://health.gov/dietaryguidelines/2015/guidelines/.

Hoolohan, C., Berners-Lee , M., McKinstry-West, J., Hewitt, C.N. 2013. Mitigating the greenhouse gas emissions embodied in food through realistic consumer choices. Energy Policy 63, 1065–1074. DOI 10.1016/j.enpol.2013.09.046.

Horgan, G. W., Perrin, A., Whybrow, S., Macdiarmid, J. I. 2016. Achieving dietary recommendations and reducing greenhouse gas emissions: modelling diets to minimise the change from current intakes. Int J Behav Nutr and Phys Activity 13, 46. DOI 10.1186/s12966-016-0370-1.

Hospido, A., Davis, J., Berlin, J., Sonesson, U. 2010. A review of methodological issues affecting LCA of novel food products. Int J Life Cycle Assess 15, 44. DOI 10.1007/s11367-009-0130-4

Huerta, A. R., Güerecab, L. P., de la Salud Rubio Lozano, M. 2016. Environmental impact of beef production in Mexico through life cycle assessment. Resources, Conservation and Recycling 109, 44–53. DOI 10.1016/j.resconrec.2016.01.020.

Ingwersen, W. W. 2012. Life cycle assessment of fresh pineapple from Costa Rica. J Cleaner Prod 35, 152-163. DOI 10.1016/j.jclepro.2012.05.035.

Irz, X., Leroy, P., Réquillart, V., Soler, L-G. 2016. Welfare and sustainability effects of dietary recommendations. Ecol Econ 130, 139–155. DOI 10.1016/j.ecolecon.2016.06.025.

ISO 14040:2006. Environmental management. Life Cycle Assessment. Principles and framework.

ISO 14044:2006. Environmental management. Life Cycle Assessment. Requirements and guidelines.

Jensen, J. D., Saxe, H., Denver, S. 2015. Cost-Effectiveness of a New Nordic Diet as a Strategy for Health Promotion. Int J Environ Res Public Health 12, 7370-7391. DOI 10.3390/ijerph120707370.

Jungbluth, N., Tietje, O., Scholz, R. W. 2000. Food purchasers: Impacts from the consumers' point of view investigated with a modular LCA. Int J Life Cycle Assess 5, 134-142. DOI 10.1065/lca2000.04.026.

Jungbluth, N., Eggenberger, S., Nowack, K., Keller, R. 2016. Life cycle assessment of meals based on vegetarian protein sources. In proc from: The 10th Int Conf Life Cycle Assess of Food (LCA Food 2016), University College Dublin (UCD), Dublin, Ireland, 19th – 21st October 2016.

Katajajuuri, J-M., Grönroos, J., Usva, K. 2014. Energy use and greenhouse gas emissions and related improvement options of the broiler chicken meat supply chain. Int J Sustain Dev 17 1, 49-61.

Kebreab, E., Liedke, A., Caro, D., Deimling, S., Binder, M., Finkbeiner, M. 2016. Environmental impact of using specialty feed ingredients in swine and poultry production: A life cycle assessment. J Anim Sci 94, 2664–2681. DOI 10.2527/jas2015-9036.

Kennedy, E. T., Ohls, J., Carlson, S., Fleming, K. 1995. The Healthy Eating Index: design and applications. J Am Diet Assoc 95, 1103–1108. DOI 10.1016/S0002-8223(95)00300-2.

Kägi, T., Zschokke, M., Dinkel, F. 2012. Nutrient based functional unit for meals. In proc from: 8th Int Conf LCA in the Agri-Food Sector, Rennes, France, 2-4 October 2012.

Labouze, E., Goffi, C., Moulay, L., Azaïs-Braesco, V., 2007a. A multipurpose tool to evaluate the nutritional quality of individual foods: nutrimap®. Public Nutr 10,7, 690-700.

Labouze, E., Goffi, C., Azaïs-Braesco, V., 2007b. "TheFoodProfiler", a Nutrient Profiling system to restrict the use of nutrition and health claims to foods with desirable nutrient profiles. SDA, 27, 413-422. doi:10.3166/sda.27.413-422

Lachance, P.A., Fisher, M.C., 1986. Educational and technological innovations required to enhance the selection of desirable nutrients. Clin Nutr 5, 257-267.

Maillot, M., Darmon, N., Darmon, M., Lafay, L., Drewnowski, A., 2007. Nutrient-dense food groups have high energy costs: an econometric approach to nutrient profiling. J Nutr 1815-1820.

Martínez-Blanco, J., Antón, A., Joan Rieradevall, J., Castellari, M., Muñoz, P. 2010. Comparing nutritional value and yield as functional units in the environmental assessment of horticultural production with organic or mineral fertilization. The case of Mediterranean cauliflower production. Int J Life Cycle Assess 16, 12–26. DOI 10.1007/s11367-010-0238-6.

Marton, S. M. R. R., Zimmermann, A., Kreuzer, M., Gaillard, G. 2017. Comparing the environmental performance of mixed and specialised dairy farms: the role of the system level analysed. J Cleaner Prod 124, 73-83. DOI 10.1016/j.jclepro.2016.02.074.

Masset, G., Soler, L-G, Vieux, F., Darmon, N., 2014. Identifying sustainable foods: the relationship between environmental impact, nutritional quality, and prices of foods representative of the French diet. J Acad Nutr Diet 114, 862-869. DOI 10.1016/j.jand.2014.02.002.

McAuliffe, G. A., Chapman, D. V., Sage, C. L. 2016. A thematic review of life cycle assessment (LCA) applied to pig production. Review article. Environ Impact Assess Rev 56, 12–22. DOI 10.1016/j.eiar.2015.08.008.

McAuliffe, G. Takahashi, T., Lee, M. R. F. 2018. Framework for life cycle assessment of livestock production systems to account for the nutritional quality of final products. Food and energy security. https://doi.org/10.1002/fes3.143

Mediterranean Diet Foundation, 2017. https://dietamediterranea.com/en/. Visited 10-8-2017.

Meier, M. S., Stoessel, F., Jungbluth, N., Juraske, R., Schader, C., Stolze, M. 2014. Environmental impacts of organic and conventional agricultural products - Are the differences captured by life cycle assessment? J Environ Manag 149, 193-208. DOI 10.1016/j.jenvman.2014.10.006.

Meier, M. S., Christen, O. 2013. Environmental Impacts of Dietary Recommendations and Dietary Styles: Germany as an Example. Environ Sci Tech 47, 877–888. DOI 10.1021/es302152v

Miller, D., Drewnowski, A., Fulgoni, V., Heaney, R.P., King, J., Kennedy, E., 2009. It is time for a positive approach to dietary guidance using nutrient density as a basic principle. J Nutr 139, 1198-1202.

Ministry of Health of Brazil, 2014. Dietary Guidelines for the Brazilian Population. Brasília: Ministério da Saúde.

Montagnese, C., Santarpia, L., Buonifacio, M., Nardelli, A., Caldara, AR, Silvestri, E. et al., 2015. European food-based dietary guidelines: a comparison and update. Nutr 31, 908–915. DOI 10.1016/ j.nut.2015.01.002.

Monteiro, C. A., Cannon, G., Moubarac, J-C, Martins, A. P. B., Martins, C. A., Garzillo, J., Canella, D. S., Baraldi, L. G., Barciotte, M., da Costa Louzada, M. L., Levy, R. B., Claro, R. M., Jaime, P. C. 2015. Dietary guidelines to nourish humanity and the planet in the twenty-first century. A blueprint from Brazil. Public Health Nutr 18, 13, 2311–2322. DOI 10.1017/S1368980015002165.

The National Nutrition Council, 2005. Finnish Nutrition Recommendations - Nutrition and Exercise to the Balance 2005. In Finnish. Valtion ravitsemusneuvottelukunta, ISBN 951-37-4501-5, 56 p.

The National Nutrition Council, 2014. Health from food - Finnish Nutrition Recommendations 2014. In Finnish. Valtion ravitsemusneuvottelukunta. ISBN 978-952-453-801-5.

Nemecek, T., Bengoa, X., Lansche, J., Mouron, P., Riedener, E., Rossi, V., Humbert, S. 2015. Methodological Guidelines for the Life Cycle Inventory of Agricultural Products. Version 3.0, July 2015. World Food LCA Database (WFLDB). Quantis and Agroscope, Lausanne and Zurich, Switzerland.

Nemecek, T., Jungbluth, N., Milà i Canals, L., Schenck, R. 2016. Environmental impacts of food consumption and nutrition: where are we and what is next? Int J Life Cycle Assess 21, 607–620. DOI 10.1007/ s11367-016-1071-3.

Nissinen, A., Grönroos, J., Heiskanen, E., Honkanen, A., Katajajuuri, J-M, Kurppa, S., Mäkinen, T., Mäenpää, I., Seppälä, J., Timonen, P., Usva, K., Virtanen, Y., Voutilainen, P. 2007. Developing benchmarks for consumer-oriented life cycle assessment-based environmental information on products, services and consumption patterns. J Cleaner Prod 15, 6, 538-549. DOI 10.1016/j.jclepro.2006.05.016.

Notarnicola, B., Hayashi, K., Curran, M. A., Huisingh, D. 2012. Progress in working towards a more sustainable agri-food industry. J Cleaner Prod 28, 1-8.

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., Sonesson, U. 2017a. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. J Cleaner Prod 140, 399-409. DOI 10.1016/j.jclepro.2016.06.071.

Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., Sala, S. 2017b. Environmental impacts of food consumption in Europe. J Cleaner Prod 140, 753-765. DOI 10.1016/j.jclepro.2016.06.080.

Nordic Council of Ministers, 2014. Nordic Nutrition Recommendations 2012: Integrating nutrition and physical activity. DOI 10.6027/Nord2014-002.

Ogino, A., Sommart, K., Subepang, S., Mitsumori, M., Hayashi, K., Yamashita, T., Tanaka, Y. 2016. Environmental impacts of extensive and intensive beef production systems in Thailand evaluated by life cycle assessment. J Cleaner Prod 112, 22-31. DOI 10.1016/j.jclepro.2015.08.110.

Pairotti, M. B., Cerutti, A. K., Martini, F., Vesce, E., Padovan, D., Beltramo, R. 2015. Energy consumption and GHG emission of the Mediterranean diet: a systemic assessment using a hybrid LCA-IO method. J Cleaner Prod 103, 507-516. DOI 10.1016/j.jclepro.2013.12.082.

Payne, C. LR, Scarborough, P., Cobiac, L. 2016. Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes? A systematic review of the literature. Public Health Nutr 19, 14, 2654-2661. DOI 10.1017/S1368980016000495.

Perignon, M., Vieux, F., Soler, L-G., Masset, G., Darmon, N. 2016. Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. Nutr Rev 75, 1, 2–17. DOI 10.1093/nutrit/nuw043.

Pernollet, Coelho, C. R. V., van der Werf, H. M. G. 2017. Methods to simplify diet and food life cycle inventories: Accuracy versus data-collection resources. J Cleaner Prod 140, 410-420. DOI 10.1016/j.jclepro.2016.06.111.

Portune, K. J., Benítez-Páez, A., Gomez Del Pulgar, E. M., Cerrudo, V., Sanz, Y. 2017. Gut microbiota, diet, and obesity-related disorders—The good, the bad, and the future challenges. Rev Mol Nutr Food Res 61, 1, 1600252. DOI 10.1002/mnfr.201600252.

Rayner, M., Scarborough, P., Boxer, A., Stockley, L., 2005. Nutrient Profiles: Development of Final Model. Final Report. British Heart Foundation Health Promotion Research Group, Department of Public Health, University of Oxford.

Reckmann, K., Blank, R., Traulsen, I., Krieter, J. 2016. Comparative life cycle assessment (LCA) of pork using different protein sources in pig feed. Arch Anim Breed 59, 27–36. DOI 10.5194/aab-59-27-2016

Risku-Norja, H., Kurppa, S., Helenius, J. 2009. Dietary choices and greenhouse gas emissions – assessment of impact of vegetarian and organic options at national scale. Prog in Ind Ecol – Int J 6, 4, 340–354. DOI 10.1504/PIE.2009.032323.

Rivera, X., C. S., Orias, N., E., Azapagic, A. 2014. Life cycle environmental impacts of convenience food: Comparison of ready and home-made meals. J Cleaner Prod 73, 294-309. DOI 10.1016/j.jclepro.2014.01.008.

Rivera, X. C. S., Azapagic, A. 2015. Life cycle costs and environmental impacts of production and consumption of ready and home-made meals. J Cleaner Prod 112, 214-228. DOI 10.1016/j.jclepro.2015.07.111.

Rockström, J., Steffen, W., Noone, K., Persson, Å.,Chapin, F. S., III, Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J. A.. 2009. A safe operating space for humanity. Nature 461, 474-475. DOI 10.1038/461472a.

Rosa, D., Figueiredo, F., Castanheira, E. G., Freire, F. 2017. Life-cycle assessment of fresh and frozen chestnut. J Cleaner Prod 140, 742-752. DOI 10.1016/j.jclepro.2016.04.064.

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D. Hauschild, M.Z. 2008. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess 13: 532. DOI 10.1007/s11367-008-0038-4.

Rosenbaum R.K., Anton A., Bengoa X., Bjørn A., Brain R., Bulle C., Cosme N., Dijkman T.J., Fantke P., Felix M., Geoghegan T.S., Gottesbüren B., Hammer C., Humbert S., Jol-liet O., Juraske R., Lewis F., Maxime D., Nemecek T., Payet J., Räsänen K., Roux P., Schau E.M., Sourisseau S., Zelm R.v., von Streit B., Wallman M., 2015. The Glasgow consensus on the delineation between pesticide emission inventory and impact assessment for LCA. Int J Life Cycle Assess 20, 6: 765-776.

Röös, E., Karlsson, H., Witthöft, C., Sundberg, C. 2015. Evaluating the sustainability of diets–combining environmental and nutritional aspects. Env Sci Pol 47, 157-166. DOI 10.1016/j.envsci.2014.12.001.

Saarinen, M., Kurppa, S., Nissinen, A., Mäkelä, J. (eds.) 2011. Choices of meals and housing in a center of environmental impacts of consumption: Final report of ConsEnv project. In Finnish. The Finnish Environ 14/2011: 97 p.

Saarinen, M. 2012. Nutrition in LCA : are nutrition indexes worth using? In: 8th Int conf life cycle assess in the agri-food sector, October 1-4, 2012 Saint-Malo, France: proc / Eds. Michael S. Corson, Hayo M. G. van der Werf. INRA. p. 385-390.

Saarinen, M., Virtanen, Y., Hyvärinen, H. 2012. LCAs for a large repertoire of Finnish outdoor plant products. In: 8th Int conf on life cycle assess in the agri-food sector, October 1-4, 2012 Saint-Malo, France: proc / Eds. Michael S. Corson, Hayo M.G. van der Werf. INRA. p. 811-812.

Saarinen, M., Silvenius, F., Kurppa, S. 2016. Hotspots in the climate impact of local food products. In: Putting LCA into practise, 10th int conf on life cycle assess of food 2016, 19th-21st October 2016: Book of abstracts. University College Dublin. pp. 1420-1423.

Salou, T., Le Mouël, C., van der Werf, H. M. G. 2017. Environmental impacts of dairy system intensification: the functional unit matters! J Cleaner Prod 140, 445-454. DOI 10.1016/j.jclepro.2016.05.019.

Sanfilippo, S., Raimondi, A., Ruggeri, B., Fino, D. 2012. Dietary vs. transport: an analysis of environmental burdens pertaining to a typical workday. Int J Cons Studies 36, 133–140. DOI 10.1111/j.1470-6431.2011.01079.x

Saxe, H., Larsen, T.M., Mogensen, L. 2012. The global warming potential of two healthy Nordic diets compared with the average Danish diet. Climatic Change 116, 249–262. DOI 10.1007/s10584-012-0495-4.

Scarborough, P., Boxer, A., Rayner, M., Stockley, L. 2007. Testing nutrient profile models using data from a survey of nutrition professionals. Public Health Nutr 10, 337–45. DOI 10.1017/S1368980007666671.

Schau, E. M., Fet, A. M., 2008. LCA studies of food products as background for environmental product declarations. Int J Life Cycle Assess 13, 3, 255-264. DOI 10.1065/lca2007.12.372.

Scheidt, D.M., Daniel, E., 2004. Composite index for aggregating nutrient density using food labels: ratio of recommended to restricted food components. J Nutr Educ Behav 36, 35-39.

Schreiner, M. 2005. Vegetable crop management strategies to increase the quantity of phytochemicals. Eur J Nutr 44: 85–94. DOI 10.1007/s00394-004-0498-7.

Seed, B. 2014. Sustainability in the Qatar national dietary guidelines, among the first to incorporate sustainability principles. Public Health Nutr 18, 13, 2303–2310. DOI 10.1017/S1368980014002110.

Semba R.D. 2017. Nutrition and Development: A Historical Perspective. In: de Pee S., Taren D., Bloem M. (eds) Nutrition and Health in a Developing World. Nutrition and Health. Humana Press, Cham. DOI 10.1007/978-3-319-43739-2_1.

Seppälä, J., Mäenpää, I., Koskela, S., Mattila, T., Nissinen, A., Katajajuuri, J-M, Härmä, T., Korhonen, M-R, Saarinen, M., Virtanen, Y. 2011. An assessment of greenhouse gas emissions and material flows caused by the Finnish economy using the ENVIMAT model. J Cleaner Prod 19, 16, 1833-1841. DOI 10.1016/j.jclepro.2011.04.021.

Silvenius, F., Grönroos, J., Kankainen, M., Kurppa, S., Mäkinen, T., Vielma, J. 2017. Impact of feed raw material to climate and eutrophication impacts of Finnish rainbow trout farming and comparisons on climate impact and eutrophication between farmed and wild fish. J Cleaner Prod 164, 1467-1473.

Silvennoinen, K., Katajajuuri, J-M., Hartikainen, H., Heikkilä, L., Reinikainen, A. 2014. Food waste volume and composition in Finnish households. British Food Journal 116, 6, 1058-1068. DOI 10.1108/BFJ-12-2012-0311.

Singh, R. K., Chang, H‑W, Yan, D., Lee, K. M., Ucmak, D., Wong, K., Abrouk, M., Farahnik, B., Nakamura, M., Zhu, T. H., Bhutani, T., Liao, W. 2017. Influence of diet on the gut microbiome and implications for human health. J Transl Med 15, 73. DOI 10.1186/s12967-017-1175-y.

Sjörs, C., Raposo, S. E., Sjölander, A., Bälter, O., Hedenus, F., Bälter, K. 2016. Diet-related greenhouse gas emissions assessed by a food frequency questionnaire and validated using 7-day weighed food records. Environ Health 15, 15. DOI 10.1186/s12940-016-0110-7.

Smedman, A., Lindmark-Månsson, H., Drewnowski, A., Edman, A-K.M 2011. Nutrient density of beverages in relation to climate impact. Food & Nutr Res, 54, 5170 – DOI: 10,340/fnr,v54i0,5170

Smetana, S., Mathys, A., Knoch, A., Heinz, V. 2015. Meat alternatives: life cycle assessment of most known meat substitutes. Int J Life Cycle Assess 20, 1254–1267. DOI 10.1007/s11367-015-0931-6.

Smitasiri, S., Uauy, R. 2007. Beyond recommendations: implementing food-based dietary guidelines for healthier populations. Food Nutr Bull 28 (Suppl 1), S141–S151. DOI 10.1177/15648265070281S112.

Song, Guobao, Li, M., Fullana-i-Palmer, P., Williamson, D., Wang, Y. 2017. Dietary changes to mitigate climate change and benefit public health in China. Sci Total Environ 577, 289–298. DOI 10.1016/j.scitotenv. 2016.10.184.

Soret, S., Mejia, A., Batech, M., Jaceldo-Siegl, K., Harwatt, H., Sabaté, J. 2014. Climate change mitigation and health effects of varied dietary patterns in real-life settings throughout North America. Am J Clin Nutr 100(suppl), 490S–5S. DOI 10.3945/ajcn.113.071589.

Soussana, J-F 2014. Research priorities for sustainable agri-food systems and life cycle assessment. J Cleaner Prod 73, 19-23. DOI 10.1016/ j.jclepro.2014.02.061.

Sonesson, U., Davis, J., Flysjö, A., Gustavsson, J., Witthöft, C. 2017. Protein quality as functional unit - A methodological framework for inclusion in life cycle assessment of food. J Cleaner Prod 140, 470-478. DOI 10.1016/j.jclepro.2016.06.115.

Sonesson, U., Mattsson, B., Nybrant, T., Ohlsson, T. 2005. Industrial Processing *versus* Home Cooking: An Environmental Comparison between Three Ways to Prepare a Meal. Ambio 34, 4–5.

Steffen, W, Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries,W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., Sörlin, S.. 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855. DOI 10.1126/science.1259855.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., de Haan, C. 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome, Italy.

Stylianou, K. S., Heller, M. S., Fulgoni III, V. L., Ernstoff, S. S., Keoleian, G. A., Jolliet, O. 2016. A life cycle assessment framework combining nutritional and environmental health impacts of diet: a case study on milk. Int J Life Cycle Assess 21, 734–746. DOI 10.1007/s11367-015-0961-0.

Temme, E. H. M., Toxopeus, I. B., Kramer, G. F. H., Brosens, M. C. C., Drijvers, J. M. M., Tyszler, M., Ocké, M. C. 2014. Greenhouse gas emission of diets in the Netherlands and associations with food, energy and macronutrient intakes. Public Health Nutr 18, 13, 2433–2445. DOI 10.1017/S1368980014002821

Tessari, P., Lante, A., Mosca, G. 2016. Essential amino acids: master regulators of nutrition and environmental footprint? Nature, Scientific Reports 6, 26074. DOI 10.1038/srep26074.

Thaler, S., Zessner, M., Weigl, M., Rechberger, H., Schilling, K., Kroiss, H. 2015. Possible implications of dietary changes on nutrient fluxes, environment and land use in Austria. Agric Systems 136, 14–29. DOI 10.1016/j.agsy.2015.01.006.

Thorning, T. K. Bertram, H. C., Bonjour, J-P., de Groot, L., Dupont, D., Feeney, E., Ipsen, R., Lecerf, J. M., Mackie, A., McKinley, M. C., Michalski, M-C., Rémond, D., Risérus, U., Soedamah-Muthu, S. S., Tholstrup, T., Weaver, C., Astrup, A., Givens, I. 2017. Whole dairy matrix or single nutrients in assessment of health effects: current evidence and knowledge gaps. Am J Clin Nutr 105, 5, 1033-1045. DOI 10.3945/ajcn.116.151548.

THL, 2017. Food composition database - Fineli ®. The Nutrition Unit of the National Institute for Health and Welfare. Available at https://fineli.fi/fineli/en/index. Visited 5-1-2018.

Tilman and Clark, 2014. Global diets link environmental sustainability and human health. Nature 515. DOI 10.1038/nature13959

Tukker, A., Goldbohm, R. A., de Koning, A., Verheijden, M., Kleijn, R., Wolf, O., Pérez-Domínguez, I., Rueda-Cantuche, J. M. 2011. Environmental impacts of changes to healthier diets in Europe. Ecol Econ 70, 1776–1788. DOI: 10.1016/j.ecolecon.2011.05.001.

Tyszler, M., Kramer, G., Blonk, H. 2014. Just eating healthier is not enough: studying the environmental impact of different diet scenarios for Dutch women (31–50 years old) by linear programming. Int J Life Cycle Assess 21, 701–709. DOI 10.1007/s11367-015-0981-9.

Ulaszewska, M. M., Luzzani, G., Pignatelli, S., Capri, E. 2017. Assessment of diet-related GHG emissions using the environmental hourglass approach for the Mediterranean and new Nordic diets. Sci Total Environ 574, 829–836. DOI 10.1016/j.scitotenv.2016.09.039.

UN, 2015. Sustainable development goals - 17 goals to transform our world. United Nations. http://www.un.org/sustainabledevelopment/sustainable-development-goals/. Visited 4-24-2017

UNEP, 2011. Towards a Life Cycle Sustainability Assessment- Making Informed Choices on Products. Available at http:// www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/life-cycle-sustainability-assessment/. Visited 4-24-2017.

UNEP/SETAC, 2009. Guidelines for Social Life Cycle Assessment of Products. Available at http://www.unep.fr/shared/publications/pdf/DTIx1164xPA-guidelines_sLCA.pdf. Visited at 4-24-2017.

UNEP/SETAC, 2015. Guidance on Organizational Life Cycle Assessment. ISBN: 978-92-807-3453-9.

Usva, K., Nousiainen, J., Hyvärinen, H., Virtanen, Y. 2012. LCAs for animal products pork, beef, milk and eggs in Finland. In: 8th Int conf life cycle assess in the agri-food sector, October 1-4, 2012 Saint-Malo, France: proc / Eds. Michael S. Corson, Hayo M. G. van der Werf. INRA. p. 845-846.

van der Werf, H. M. G., Salou, T. 2015. Economic value as a functional unit for environmental labelling of food and other consumer products. J Cleaner Prod 94, 394-397. DOI 10.1016/j.jclepro.2015.01.077.

van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., Vellinga, P. 2014. Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy 44, 36–46. DOI 10.1016/j.foodpol.2013.11.002.

Virtanen, Y., Kurppa, S., Saarinen, M., Katajajuuri, J-M, Usva, K., Mäenpää, I., Mäkelä, J., Grönroos, J., Nissinen, A. 2011. Carbon footprint of food: approaches from national input-output statistics and a LCA of a food portion. J Cleaner Prod 19, 16, 1849-1856. DOI 10.1016/j.jclepro.2011.07.001.

Volatier, J-L, Biltoft-Jensen, A., De Henauw, S. et al. 2007. A new reference method for the validation of the nutrient profiling schemes using dietary surveys. Eur J Nutr 46(suppl 2), 29–36. DOI 10.1007/s00394-007-2004-5.

Waijers, P. M. C. M., Feskens, E. J. M., Ocké, M. C. 2007. A critical review of predefined diet quality scores. Review Article. Br J Nutr 97, 219–231. DOI 10.1017/S0007114507250421

Warde, A., 2005. Consumption and theories of practice. J Cons Culture 5, 2, 131-153. DOI 10.1177/1469540505053090.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B. 2016. The EcoInvent database version 3 (part I): overview and methodology. Int J Life Cycle Assess, [online] 21, 9,1218–1230.

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., Ferreira de Souza Dias, B., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G.M., Marten, R., Myers, S. S., Nishtar, S., Osofsky, S. A., Pattanayak, S. K., Pongsiri, M. J. Romanelli, C., Soucat, A., Vega, J., Yach D. 2014. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Published online July 16, 2014. DOI 10.1016/S0140-6736(15)60901-1

Williams, H., Wikström, F. 2011. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. J Cleaner Prod 19, 43-48. DOI 10.1016/j.jclepro.2010.08.008.

Zelman, K., Kennedy, E., 2005. Naturally nutrient rich: putting more power on Americans' plates. Nutr Today 40, 60-68.

zu Ermgassen, E. K. H. J., Phalan, B., Green, R. E., Balmford, A. 2016. Reducing the land use of EU pork production: where there's swill, there's a way. Food Policy 58, 35–48. DOI 10.1016/j.foodpol.2015.11.001